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A NOVEL FAMILY OF BETA SUB-UNIT PROTEINS
FROM A VOLTAGE-GATED SODIUM CHANNEL,
NUCLEIC ACIDS ENCODING THEM AND
THERAPEUTIC OR DIAGNOSTIC USES THEREOF
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CLAIM OF PRIORITY

Commissioner for Patents
Washington, D.C. 20231

Sir:

Applicants hereby claim priority under 35 U.S.C. §119, from International Application

PCT/EP00/01783. A certified copy is enclosed.

Acknowledgment of the claim of priority and of the receipt of said certified copy is
respectfully requested.

Respectfully submitted,

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Bescheinigung

Certificate

Attestation

Die angehefteten Unterlagen stimmen mit der ursprünglich eingereichten Fassung der auf dem nächsten Blatt bezeichneten internationalen Patentanmeldung überein.

The attached documents are exact copies of the international patent application described on the following page, as originally filed.

Les documents fixés à cette attestation sont conformes à la version initialement déposée de la demande de brevet international spécifiée à la page suivante.

Den Haag, den
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10. 12. 01

Der Präsident des Europäischen Patentamts
Im Auftrag
For the President of the European Patent Office
Le Président de l'Office européen des brevets
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NATHALIE KUIPER

Patentanmeldung Nr. PCT/EP 00/01783
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Titre de l'invention: GATED SODIUM CHANNEL, NUCLEIC ACIDS ENCODING THEM AND
THERAPEUTIC OR DIAGNOSTIC USES THEREOF.

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TITLE OF THE INVENTION

**A novel family of beta sub-unit proteins from a voltage-gated sodium
channel, nucleic acids encoding them and
therapeutic or diagnostic uses thereof.**

FIELD OF THE INVENTION

The present invention relates to a novel family of beta sub-unit proteins from a voltage-gated sodium channel, and particularly the human and the rat beta sub-units.

The invention also deals with the use of the $\beta 3$ sub-unit polypeptide or a fragment thereof as well as of the nucleic acids encoding same for therapeutic, diagnostic and screening purposes.

BACKGROUND OF THE INVENTION

Sodium channels play a central role in physiology. They transmit depolarising impulses rapidly throughout cells and cell networks, thereby enabling co-ordination of higher processes from cognition to locomotion. The ion permeability and voltage sensing is primarily determined by the alpha sub-unit of the sodium channel complex as this forms the pore. There are at least two major classes and at least eight genes encoding sodium channels.

Voltage-dependent Na^+ channels have long been recognised as targets for anti-arrhythmic and local anaesthetic drugs. Since the mid-1980s, Na^+ channels have become widely accepted as the primary target of anticonvulsants with pharmacological profiles similar to those of phenytoin, carbamazepine, and lamotrigine.

Alteration of ion channel function is an important pathophysiological mechanism of various familial muscle diseases. Na^+ channel mutations underlie the aberrant excitability characteristic of some skeletal muscle myotonias and paralysis, as well as chromosome 3-linked long-QT syndrome, an inherited cardiac arrhythmia. In general, these mutations disable inactivation of the Na^+ channel, producing either repetitive action potential firing (myotonia) or electrical silence (flaccid paralysis) in skeletal muscles. A similar defect in the cardiac Na^+ channel produces action potential prolongation and a predisposition to repetitive electrical activity in the heart leading to polymorphic ventricular tachycardia.

Additional determinants of sodium channel function are the presence or absence of auxiliary $\beta 1$ and 2 sub-units. These are important modulators of Na^+ channel function. Biochemical studies first revealed the existence of two distinct sub-units ($\beta 1$ and $\beta 2$) associated with the brain Na^+ channel. Antibodies directed to the α or β sub-unit appeared to immunoprecipitate the entire brain Na^+ channel complex with a sub-unit stoichiometry of $1\alpha: 1\beta 1: 1\beta 2$. The $\beta 1$ sub-unit is non-covalently associated, while $\beta 2$ is linked by a disulphide bond to the α sub-unit. The $\beta 1$ and $\beta 2$ sub-units have been cloned and the deduced primary structures indicate that they are unrelated proteins of molecular weights of 23 and 21 kDa, respectively. The predicted transmembrane topology of the sub-units is similar: each contains a small carboxy-terminal cytoplasmic domain, a single membrane-spanning segment, and a large amino-terminal extracellular domain with several consensus sites for N-linked glycosylation.

Expression of $\beta 2$ with neuronal sub-units in *Xenopus* oocytes increased the current amplitude, modulated gating and increased the membrane capacitance. Co-expression of $\beta 1$ sub-units with either neuronal or skeletal muscle sub-units in oocytes also produced clear-cut effects on channel function. The current density increased, activation and inactivation gating were accelerated, and the steady-state inactivation curves were shifted in the hyperpolarizing direction. The mRNA encoding the $\beta 1$ sub-unit appears to be widely expressed and clearly forms an important component of neuronal and skeletal muscle Na^+ channels. It has recently been established that $\beta 1$ sub-units modify the interactions of neurotoxins and local anaesthetics with the rat brain α sodium channel.

Until recently there was no known linkage of a phenotype with the β sub-units. However, a mutation in the $\beta 1$ sub-unit gene SCN1B has been shown to be associated with Febrile seizures and generalised epilepsy.

All the known sub-units of the Na^+ channel are modified by glycosylation. The $\beta 1$, $\beta 2$ and brain and muscle sub-units are heavily glycosylated, with up to 40% of the mass being carbohydrate. In contrast, the cardiac sub-unit contains only 5% of sugar by weight. Sialic acid is a prominent component of the N-linked carbohydrate of the Na^+ channel. The addition of such a highly charged carbohydrate has predictable effects on the voltage dependence of gating through alteration of the surface charge of the channel protein. Neuraminidase treatment to remove sialic acid from expressed skeletal muscle channels produces a depolarizing shift of steady-state inactivation. It has also been shown that co-

translational glycosylation is essential for the maintenance of cell surface expression of the Na⁺ channel in neurones and Schwann cells. Inhibition of glycosylation by tunicamycin reversibly decreases the number of STX binding sites on neuroblastoma cells. Tunicamycin also inhibits palmitation, sulphation and disulphide attachment of the $\beta 2$ sub-unit, preventing the assembly of functional Na⁺ channels.

The modulation of the voltage gated sodium channel was thought to be through the $\beta 1$ sub-unit. However, analysis of the distribution of these sub-units in human and rat indicates an asymmetric distribution. This poses the question as to what other mechanisms are employed to impart correct function to the voltage gated sodium channel.

The inventors have discovered a distinct second auxiliary regulatory sub-unit $\beta 3$ which could at least partially explain this discrepancy.

SUMMARY OF THE INVENTION

The invention relates to a purified or isolated nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel or a sequence complementary thereto.

The invention also concerns a $\beta 3$ sub-unit polypeptide or a peptide fragment thereof as well as antibodies specifically directed against such $\beta 3$ sub-unit polypeptide or peptide fragment.

Oligonucleotide probes or primers specifically hybridizing to a nucleic acid encoding a $\beta 3$ sub-unit or to a sequence complementary thereof are also part of the invention as well as DNA amplification and detection methods using said primers and probes.

A further object of the invention consists of recombinant vectors comprising any of the nucleic acid sequence described herein, and in particular recombinant vectors comprising a nucleic acid sequence encoding a $\beta 3$ sub-unit of the invention, the invention also encompasses host cells and transgenic non-human mammals comprising said nucleic acid sequences or recombinant vectors.

The present invention is also directed to a method of screening for agonist and antagonist molecules or substances of sodium channels as well as to gene therapy methods involving selective addition or removal of the $\beta 3$ sub-unit nucleic acid sequence in a genome, particularly via an anti-sense technology.

The invention also pertains to methods for the diagnosis of diseases states involving a dysfunction of a voltage-gated sodium channel through analysis, with either the oligonucleotides or antibodies of the invention, of the expression of the $\beta 3$ sub-unit. Conditions which involve the $\beta 3$ sub-unit include pain, epilepsy, stroke, ischemia and heart disease. Furthermore, the human $\beta 3$ gene has been mapped to chromosome 11q 23.3. The genes for $\beta 2$ and the human N-CAM gene, which contains a V-type Ig domain, are also localised close to this region (Eubanks, J et al, 1997 & Nguyen, C. et al, 1986). Diseases which map to 11q 23.3 include Jacobsen Syndrome, Familial Nonchromaffin Paraganglioma, Phenylketonuria due to PTS deficiency and Charcot Marie Tooth disease. Therefore, characterisation of the modulation of the expression of $\beta 3$ could be useful for the diagnosis of these diseases.

The invention will be described hereinafter more in details and will be illustrated by the following figures:

Figure 1: Sequence alignment of the human and rat $\beta 3$ sub-unit coding sequences.

Upper line: coding sequence of the human $\beta 3$ sub-unit.

Middle line: coding sequence of the rat $\beta 3$ sub-unit.

Lower line: consensus sequence containing the nucleotides that are common to both the human and rat $\beta 3$ sub-units.

Figure 2: Tissue expression of $\beta 3$ and $\beta 1$ subunits in rat by Polymerase Chain Reaction.

Figure 3: In situ distribution of sodium channel subunits in adult rat brain. X-ray autoradiographs of separate sagittal sections of rat brain (taken from the same animal) showing the distribution of rat αIIA (a,b,c); rat $\beta 1$ (d,e,f) and rat $\beta 3$ (g,h,i) mRNA transcripts as revealed by in situ hybridisation with specific oligonucleotide probes. Control reactions with 100-fold excess unlabelled probes are shown for αIIA (c); $\beta 1$ (f) and $\beta 3$ (i). Slides were exposed to X-ray film for 10 days. Dark areas indicate high expression levels. Cb, cerebellum; Ctx, cortex; CP, caudate putamen.

Figure 4: Amino acid sequence alignment of the human and rat $\beta 3$, rat $\beta 1$ sub-unit and rat myelin P0 protein.

Line-1: Amino acid sequence of rat $\beta 3$
 Line-2: Amino acid sequence of human $\beta 3$
 Line-3: Amino acid sequence of rat $\beta 1$
 Line-4: Amino acid sequence of rat myelin P0

Figure 5: Three dimensional structure of the extra-cellular domain of the $\beta 3$ sub-unit.

Figure 6: Na^+ current curves in oocytes expressing either the IIA α sub-unit alone, or IIA α and $\beta 1$ or $\beta 3$ sub-units. Inward Na^+ currents were evoked by applying 5 mV depolarizing pulses from a holding potential of -100 mV, from -80 mV to +30 mV. **a.** Na^+ currents recorded from oocytes expressing IIA α subunit alone. Inactivation at -10 mV was best-fitted with a double exponential function, where $\tau_1 = 2 \pm 0.3$ ms and $\tau_2 = 12.7 \pm 2.4$ ms ($n = 4$). **b.** Na^+ currents recorded from oocytes coexpressing IIA α and $\beta 1$ subunits. Inactivation was best-fitted with a double exponential function, where $\tau_1 = 1.3 \pm 0.3$ ms and $\tau_2 = 22.7 \pm 7.7$ ms at -10 mV ($n = 4$). **c.** Na^+ currents recorded from oocytes coexpressing IIA₂ α and the $\beta 3$ subunits. Inactivation was best-fitted with a double exponential function, where $\tau_1 = 1 \pm 0.1$ ms and $\tau_2 = 23.8 \pm 6.3$ ms at -10 mV ($n = 4$).

Figure 7: Na^+ current curves in oocytes expressing either the IIA α sub-unit alone, or IIA α and $\beta 1$ or $\beta 3$ sub-units.

DETAILED DESCRIPTION OF THE INVENTION

The inventors have found a novel family of beta sub-unit proteins that cooperate with at least one α sub-unit of voltage-gated sodium channels to form an active sodium channel. This novel beta sub-unit family has been termed $\beta 3$ and can be identified as such through common structural sequence features, such as a high homology within the sequences that will be described hereafter.

The inventors have found novel nucleic acid sequences encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel. They have shown that this $\beta 3$ sub-unit was biologically functional and that co-expression of the $\beta 3$ sub-unit with an $\alpha 2$ sub-unit from a voltage-gated sodium channel significantly increases the rate of inactivation of the channel, as compared with the expression of the $\alpha 2$ sub-unit alone. Moreover, co-expression of the $\beta 3$ sub-unit of the invention with an $\alpha 2$ sub-unit increases the rate of recovery from inactivation of the sodium channel as compared with the expression of the $\alpha 2$ sub-unit alone.

The inventors have thus demonstrated that the $\beta 3$ sub-unit of the invention is involved in the regulation of the sodium currents induced by the voltage-gated sodium channels. They have also determined that the $\beta 3$ sub-units of the invention may be valuable targets for drugs capable of up regulating or down regulating the activity of voltage-gated sodium channels, in particular drugs designed for preventing or treating pain, epilepsy (typically febrile seizures and generalized epilepsy), stroke, ischemia, heart disease, Jacobsen Syndrome, Familial Nonchromaffin Paraganglioma, Phenylketonuria due to PTS deficiency and Charcot Marie Tooth disease. Appropriate modulation of $\beta 3$ may therefore be taken into account in the treatment of such diseases.

In another aspect of the present invention, the nucleic acids encoding the $\beta 3$ sub-unit may be used to design polynucleotides that can interfere with the functional expression of the $\beta 3$ sub-unit both *in vitro* and *in vivo* and hence also be useful in the treatment of diseases set forth above.

NUCLEOTIDE SEQUENCES ENCODING $\beta 3$

A first object of the present invention consists of a purified or isolated nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel, or a sequence complementary thereto. Preferred nucleic acids encoding a $\beta 3$ sub-unit include those isolated from rat and human brain, preferably, those of SEQ ID N°3 and SEQ ID N°4.

Using total mRNA from wild type PC12 and variant PC12 cell lines, the inventors have isolated the cDNA encoding the rat $\beta 3$ sub-unit. From the rat $\beta 3$ sub-unit cDNA

sequence information, the inventors have also isolated and cloned the human cDNA encoding the human $\beta 3$ sub-unit.

As shown in figure 1, the coding sequences (ORF) of the rat and human $\beta 3$ sub-units are highly homologous, with only 70 non identical nucleotides out of a total length of 648 nucleotides (> 89% nucleotide identity between the two coding sequences). Hence, the inventors believe that nucleic acids encoding $\beta 3$ in other mammalian species will share a strong nucleotide identity with the corresponding rat and human nucleotide sequences.

Consequently, a further object of the invention consists of a purified or isolated nucleic acid having at least 90%, preferably 95%, more preferably 98%, and most preferably 99% nucleotide identity with the nucleotides sequence of SEQ ID N°3, or a sequence complementary thereto.

The invention also deals with a purified or isolated nucleic acid comprising a sequence encoding the Open Reading Frame (ORF) of a $\beta 3$ sub-unit from a voltage-gated channel present in the rat brain, such sequence having at least 90%, preferably 95%, more preferably 98% and most preferably 99% with the polynucleotide beginning at the nucleotide located in position 363 and ending at the nucleotide located in position 1010 of the nucleotide sequence of SEQ ID N°3.

The invention relates also to a purified or isolated nucleic acid having at least 90%, preferably 95%, more preferably 98%, and most preferably 99% nucleotide identity with the nucleotide sequence of SEQ ID N°4, or a sequence complementary thereto.

The invention is also directed to a purified or isolated nucleic acid comprising a sequence encoding the Open Reading Frame (ORF) of a $\beta 3$ sub-unit from a voltage-gated channel present in the human brain, such sequence having at least 90%, preferably 95%, more preferably 98% and most preferably 99% with the polynucleotide beginning at the nucleotide located in position 376 and ending at the nucleotide located in position 1023 of the nucleotide sequence of SEQ ID N°4.

Another object of the invention consists of a purified or isolated nucleic acid encoding a polypeptide having at least 80%, preferably 90%, more preferably 95%, and most preferably 98% aminoacid identity with the rat polypeptide of the aminoacid sequence of SEQ ID N°1 or with a peptide fragment thereof, or a sequence complementary thereto.

The invention further concerns a purified or isolated nucleic acid encoding a polypeptide having at least 80%, preferably 90%, more preferably 95%, and most preferably 98% aminoacid identity with the human polypeptide of the aminoacid sequence of SEQ ID N°2 or with a peptide fragment thereof or a sequence complementary thereto.

5

The term " isolated " requires that the material be removed from its original environment (e.g. the natural environment if it is naturally occurring). For example, a naturally occurring polynucleotide or a peptide present in a living animal is not isolated, but the same polynucleotide or peptide, separated from some or all of the coexisting materials in the natural system, is isolated.

10

Such polynucleotide can be part of a vector and/or such polynucleotide or peptide can be part of a composition, and still be isolated in that the vector or composition is not a part of its natural environment.

15

The term " purified " does not require absolute purity; rather , it is intended as a relative definition.

Purification of starting materials or natural materials to at least one order of magnitude, preferably two or three orders, and more preferably four or five orders of magnitude is expressly contemplated.

20

Throughout the present specification, the expression " nucleotide sequence " may be employed to designate indifferently a polynucleotide or a nucleic acid. More precisely, the expression " nucleotide sequence " encompasses the nucleic material itself and is not restricted to the sequence information (i.e. the succession of letters chosen among the four base letters) that biochemically characterizes a specific DNA or RNA molecule.

25

As used interchangeably herein, the term " oligonucleotides ", " nucleic acids " and " polynucleotides " include RNA, DNA, or RNA/DNA hybrid sequences of more than one nucleotide in either single chain or duplex form.

30

Further to its general meaning understood by the one skilled in the art, the term " nucleotide " is also used herein to encompass modified nucleotides which comprise at least one of the following modifications: (a) an alternative linking group, (b) an analogous form of purine, (c) an analogous form of pyrimidine, or (d) an analogous sugar. For examples of analogous linking groups, purines, pyrimidines, and sugars, see for example PCT publication N°WO 95/04064.

The polynucleotide sequences of the invention may be prepared by any known method, including synthetic, recombinant, or a combination thereof as well as through any purification methods known in the art.

5 β 3 NUCLEOTIDE FRAGMENTS AND ASSAYS

The invention also encompasses polynucleotide fragments of a nucleic acid encoding a β 3 sub-unit of a voltage-gated sodium channel as described herein, that may be useful either to express a peptide fragment, preferably a biologically active peptide
10 fragment, of this β 3 sub-unit, as nucleic acid primers or probes for amplification or detection purposes, or as antisense nucleotides able to regulate the expression of the corresponding gene.

Consequently, the present invention also concerns a purified or isolated
15 polynucleotide comprising at least 10 consecutive nucleotides of a nucleic acid encoding a β 3 sub-unit from a voltage-gated sodium channel described herein, preferably at least 10 consecutive nucleotides of any one of the nucleotide sequences of SEQ ID N°3 or 4, or a sequence complementary thereto.

Preferred polynucleotides include those encoding peptides selected from SEQ ID
20 N° 5 to 32 and SEQ ID 46 and 47. Other preferred polynucleotides include those of SEQ ID N° 35 to 43.

The nucleic acids described above consist of a contiguous span which ranges in length from about 10, 12, 15, 18 or 20 to about 25, 35, 40, 50, 70, 80, 100, 250, 500 or
25 1000 nucleotides, or be specified as being 10, 12, 15, 18, 20, 25, 35, 40, 50, 100, 200, 250, 500 or 1000 nucleotides in length.

These nucleic acids are useful as probes in order to detect the presence of at least a copy of a nucleotide sequence encoding a β 3 sub-unit from a voltage-gated sodium channel, more particularly the presence of at least a copy of a nucleotide sequence of SEQ
30 ID N°3 or SEQ ID N°4 or a sequence complementary thereto or a fragment or a variant thereof in a sample. They can also be used to express a selected peptide of the invention.

The nucleic acid probes of the invention may also be used for the analysis of the expression levels and patterns of the $\beta 3$ sub-unit, such as described in the PCT Application N°WO 97/05 277, the entire contents of which is herein incorporated by reference.

5 Quantitative analysis of the $\beta 3$ sub-unit expression may also be performed using assays, i.e. a substrate on which has been bound a plurality of nucleic acid probes according to the invention, these probes being either randomly distributed on the substrate or arranged following a one dimensional, two dimensional or multidimensional arrangement. Such assays may additionally comprise nucleic acid probes that do not
10 hybridize with a $\beta 3$ sub-unit DNA or RNA, such as for example probes specific for $\alpha 2$, $\beta 1$ or $\beta 2$ sodium channel sub-unit RNA or DNA sequences. Suitable techniques are, for example, those described by Schena et al (1995; 1996), and also by Sosnowsky et al., (1997), the disclosures of which are herein incorporated by reference.

15 The invention further deals with a purified or isolated nucleic acid that hybridizes, under stringent hybridization conditions, with a nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel, or a sequence complementary thereto.

As an illustrative embodiment, stringent hybridization conditions can be defined as follows:

20 The hybridization step is conducted at 65°C in the presence of 6 x SSC buffer, 5 x Denhardt's solution, 0.5 % SDS and 100 μ g/ml of salmon sperm DNA.

The hybridization step is followed by four washing steps:

- two washings during 5 minutes, preferably at 65°C in a 2 x SSC and 0.1% SDS buffer;

25

- one washing during 30 minutes, preferably at 65°C in a 2 x SSC and 0.1% SDS buffer;

- one washing during 10 minutes, preferably at 35°C in a 0.1 x SSC and 0.1% SDS buffer,

it being understood that the hybridization conditions defined above are suitable for nucleic
30 acids of approximately twenty nucleotides in length and that these conditions may be also adapted for shorter or longer nucleic acids, according to techniques well known in the art, for example those described by Sambrook et al. (1989).

The appropriate length for probes under a particular set of assay conditions may be empirically determined by the one skilled in the art. The probes can be prepared by any suitable method, including, for example, cloning and restriction of appropriate sequences and direct chemical synthesis by a method such as the phosphodiester method of Narang et al.(1979), the phosphodiester method of Brown et al., (1979), the diethylphosphoramidite method of Beaucage et al. (1981) and the solid support method described in the application N°EP-0 707 792. The disclosures of all these documents are incorporated herein by reference.

Any of the nucleic acids of the present invention can be labelled, if desired, by incorporating a label detectable by spectroscopic, photochemical, biochemical, immunochemical, or chemical means.

For example, useful labels include radio-active substances (^{32}P , ^{35}S , ^3H , ^{125}I), fluorescent dyes (5-bromodesoxyuridin, fluorecein, acetylaminofluoren, digoxigenin) or biotin. Examples of non-radioactive labelling of nucleic acid fragments are described in French Patent N°FR-78 10975 or by Urdea et al. (1988) or Sanchez-Pescador et al. (1988).

Advantageously, the probes according to the present invention may have structure and characteristics such that they allow signal amplification, such structural characteristics being, for example, branched DNA probes as those described by Urdea et al. (1991).

Any of the nucleic acid probes of the invention can be conveniently immobilized on a solid support. Solid supports are known those skilled in the art and include the walls of wells of a reaction tray, test tubes, polystyrene beads, magnetic beads, nitro-cellulose strips, membranes, microparticules such as latex particles, sheep red blood cells, duracytes and others.

The nucleic acids of the invention and particularly the nucleotide probes described above can thus be attached to or immobilized on a solid support individually or in groups of at least 2, 5, 8, 10, 12, 15, 20 or 25 distinct nucleic acids of the invention to a single solid support.

In a specific embodiment of a support on which nucleic acid probes of the invention are immobilized, such a support may also contain other immobilized probes, preferably probes that hybridize specifically with a nucleic acid encoding a sub-unit from a voltage-gated sodium channel, or a variant thereof, or a sequence complementary thereto, and more

preferably with a nucleic acid encoding an α sub-unit, most preferably an $\alpha 2$ sub-unit of a voltage-gated sodium channel.

The invention also encompasses nucleic acid probes comprising a nucleotide
5 sequence included in any one of the sequences of SEQ ID N°3 and 4 as well as the preferred polynucleotides referred to above wherein at least one nucleotide substitution has been made in order to create a mismatch between this probe and the complementary nucleotide sequence included in any one of SEQ ID N°3 and SEQ ID N°4 to be detected. Under suitable hybridization conditions, these probes will not hybridize anymore with
10 anyone of the nucleotide sequences of SEQ ID N°3 and SEQ ID N°4 or a fragment thereof or a sequence complementary thereto, but will hybridize only with nucleotide sequences which are exactly complementary to the polynucleotide comprised in these probes.

This specific embodiment of the nucleic acid probes of the invention may allow the detection of nucleotide polymorphisms within a nucleic acid sequence encoding a $\beta 3$ sub-
15 unit of voltage-gated sodium channel, more specifically in a nucleic acid encoding a $\beta 3$ sub-unit voltage-gated sodium channel from human or rat, and more preferably a nucleic acid of any one of the sequences SEQ ID N°3 and SEQ ID N°4, or a sequence complementary thereto.

Such probes can allow the one skilled in the art to detect mutations occurring in a
20 nucleic acid encoding a $\beta 3$ sub-unit of the invention, more preferably a nucleic acid encoding a $\beta 3$ sub-unit from rat of human, and most preferably a nucleic acid or any one of SEQ ID N°3 and SEQ ID N°4.

The invention also deals with a method for detecting the presence of a nucleic acid
25 encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel, a fragment or a variant thereof or a complementary sequence thereto in a sample, said method comprising the following steps:

(a) bringing into contact a nucleic acid probe or a plurality of nucleic acid probes of the invention which can hybridize with a nucleotide sequence included in a nucleic acid
30 encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel, or a fragment a variant thereof or a complementary sequence thereto, and a sample to be assayed;

(b) detecting the hybrid complex formed between the probe or the plurality of probes and a nucleic acid in the sample.

5 In a first preferred embodiment, the nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel to be detected is preferably a rat or human $\beta 3$ sub-unit, and more preferably a nucleic acid selected from the group consisting of the nucleotide sequences of SEQ ID N°3 and SEQ ID N°4.

In a second preferred embodiment of this detection method, the nucleic acid probe or the plurality of nucleic acid probes are labelled with a detectable molecule.

10 In a third preferred embodiment of the method, the nucleic acid probe or the plurality of nucleic acid probes are immobilized on a substrate.

In a fourth preferred embodiment of the method, the nucleic acid contained in the sample is made available to hybridization before step (a), by any conventional procedure well known from the one skilled in the art.

15

The invention further concerns a kit for detecting the presence of a nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel, a fragment or a variant thereof or a complementary sequence thereto in a sample, wherein said kit comprises:

- (a) a nucleic acid probe or a plurality of a nucleic acid probes as described above;
- 20 (b) optionally, a reagent necessary for performing the hybridization reaction.

In a first preferred embodiment of the detection kit, the nucleic acid to be detected encodes a human or rat $\beta 3$ sub-unit, and consists preferably of any one of the nucleotide sequences of SEQ ID N°3 and SEQ ID N°4, a fragment or a variant thereof, or a sequence complementary thereto.

25 In a second preferred embodiment of the detection kit, the nucleic acid probe or the plurality of nucleic acid probes are labelled with a detectable molecule.

In a third preferred embodiment of the detection kit, the nucleic acid probe or the plurality of nucleic acid probes are immobilized on a substrate.

30 The invention is also directed to a polynucleotide primer hybridizing, under the stringent hybridization conditions described herein, with a nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel of the invention, preferably a rat or a human $\beta 3$ sub-unit, and more preferably a nucleotide sequence selected from the group consisting of SEQ ID N°3 and SEQ ID N°4.

As an illustrative example, primers according to the present invention may comprise, or may consist of a polynucleotide selected from the group consisting of the nucleotide sequences of SEQ ID N°33, SEQ ID N°34, SEQ ID N° 35, SEQ ID N° 42 and SEQ ID N° 43. The use of a pair of primers, for example respectively comprising, or
5 consisting of the nucleotide sequences of SEQ ID N°33 and SEQ ID N°34 allows the one skilled in the art to amplify the whole nucleic acid sequences encoding either the human $\beta 3$ sub-unit or the rat $\beta 3$ sub-unit of the invention.

In a specific embodiment of a primer according to the invention, such a primer may comprise a 3' end nucleotide which is not exactly complementary to a target sequence
10 included in anyone of the nucleotide sequences of SEQ ID N°3 or SEQ ID N°4, or a sequence complementary thereto.

According to this specific embodiment of a primer according to the invention, such a primer comprises a 3' end nucleotide chosen in such a way as to allow hybridization of the primer, and thus the possibility of further elongation, only when a given variant of a $\beta 3$ sub-unit of the invention is present in the sample containing the target sequence to be
15 amplified, this variant $\beta 3$ sub-unit nucleic acid sequence corresponding to a genome polymorphism. Particularly, preferred primers encompassed in this specific embodiment will then exclusively hybridize with a given variant of a $\beta 3$ sub-unit of the invention, and more preferably with a $\beta 3$ sub-unit of the invention for which a linkage with a detectable
20 phenotype, caused by a disfunction in a voltage-gated sodium channel, and more preferably with pain, epilepsy, stroke and ischemia, heart disease, Jacobsen Syndrome, Familial Nonchromaffin Paraganglioma, Phenylketonuria due to PTS deficiency and Charcot Marie Tooth disease has been shown.

$\beta 3$ POLYPEPTIDES

Another object of the present invention consists of a purified or isolated polypeptide comprising the aminoacid sequence of the $\beta 3$ sub-unit from a voltage-gated sodium
30 channel, or a peptide fragment or a variant thereof.

In a first embodiment, the polypeptide comprises the aminoacid sequence of the $\beta 3$ sub-unit from a voltage-gated sodium channel present in the rat brain or a peptide fragment

or a variant thereof. A particularly preferred polypeptide is the polypeptide of SEQ ID N°1

In a second preferred embodiment, the polypeptide comprises the aminoacid sequence of the $\beta 3$ sub-unit or from a voltage-gated sodium channel present in the human brain, or a peptide fragment or variant thereof. A particularly preferred polypeptide is the polypeptide of SEQ ID N°2.

As shown in figure 4, the amino acid sequences of the rat and human $\beta 3$ sub-units have a very strong sequence similarity, with only three non identical aminoacids out of a total length of 191 amino acids when the signal sequence is included (>98% aminoacid identity between the two polypeptides). The sequence similarity between the two polypeptides is even higher (>99% aminoacid identity) if the 24 aminoacid sequence of the signal peptide is not included in the analysis. Thus, the inventors also believe that the $\beta 3$ polypeptide in other mammalian species will share a strong amino acid identity with the corresponding rat and human amino acid sequences.

Hence, the present invention concerns a polypeptide comprising an aminoacid sequence having at least 90%, preferably 95%, more preferably 98%, and more preferably 99% amino acid identity with the aminoacid sequence of SEQ ID N°1 or a peptide fragment thereof.

Also within the scope of the present invention is a polypeptide comprising an aminoacid sequence having at least 90%, preferably 95%, more preferably 98%, and most preferably 99% aminoacid identity with the aminoacid sequence of SEQ ID N°2, or a peptide fragment thereof.

$\beta 3$ PEPTIDE FRAGMENTS

The invention also relates to specific fragments of the $\beta 3$ polypeptide which can be useful for example in diagnostic and ligand screening applications.

Particularly, preferred $\beta 3$ fragments of interest have been selected from an analysis of the aminoacid sequence of the $\beta 3$ protein. Figure 4 comprises annotations on the $\beta 3$

aminoacid sequence indicating critical regions of interest and figure 5 shows the three dimensional structure of $\beta 3$.

$\beta 3$ first forms a linear extra-cellular N-terminal domain with a single
 5 membrane spanning sequence. The 24 N-terminal amino acids of this portion of the $\beta 3$ protein sequence shown in figure 4 as amino acids -1 to -24 include a hydrophobic region preceded by a positive residue which are typical features of a signal sequence. The location of the probable cleavage site is indicated in figure 4 and is supported by the presence of cysteine at position -3. The inventors believe that the $\beta 3$ signal and
 10 cleavage sequences play a crucial role in the transportation of $\beta 3$ and therefore may be crucial targets for the development of therapeutics and detection. These sequences therefore fall within the scope of the present invention.

Preferred peptides encoding the entire or partial $\beta 3$ human or rat signal and cleavage sequence, include those of SEQ ID N° 5 and SEQ ID N° 6 which comprise
 15 the entire signal and cleavage sequence (amino acids -1 to -24 of the rat and human $\beta 3$ sequences of figure 4). Other preferred peptides include those of SEQ ID N° 7 and SEQ ID N° 8 (aminoacids -6 to -24 of the rat and human $\beta 3$ sequences of figure 4), those of SEQ ID N° 9 and SEQ ID N° 10 (amino acids -13 to -24 of the rat and human $\beta 3$ sequences of figure 4), those of SEQ ID N° 11 and SEQ ID N° 12
 20 (aminoacids -3 to -17 of the rat and human $\beta 3$ sequences of figure 4), those of SEQ ID N° 13 and SEQ ID N° 14 (aminoacids -1 to -5 of the rat and human $\beta 3$ sequences of figure 4) and those of SEQ ID N° 15 and SEQ ID N° 16 (aminoacids -1 to -11 of the rat and human $\beta 3$ sequences of figure 4).

25 The three-dimensional structure of the central portion of the extra-cellular domain of $\beta 3$, which includes aminoacids 1 to 135 of figure 4, is shown in figure 5. It was determined using as an initial model the structure of the extra-cellular domain of myelin P_0 . Without wishing to be bound by any particular theory, the inventors believe that this model may provide a relatively accurate determination of the $\beta 3$
 30 structure, as the extra-cellular domain of $\beta 1$, $\beta 2$ and $\beta 3$ shows homology to proteins which adopt a V-type Ig fold. The V-type Ig fold of myelin P_0 comprises ten β -strands (labelled A, A', B, C, C', C'', D, E, F and G) that form two anti-parallel sheets packed

face to face. The corresponding β strands of the $\beta 3$ protein are shown in figure 5. The inventors believe that each of these strands could have a significant impact on $\beta 3$ activity or detection and hence these fall within the scope of the present invention.

5 The myelin P_0 model first predicts disulfide bonds at positions C21-96 and C2-24 of $\beta 3$. The former is conserved in all V-type Ig domains and is likely to be structurally important as its disruption in $\beta 1$ causes an inherited epilepsy syndrome. The latter is an unusual feature in Ig domains but its probable conservation in $\beta 1$ suggests functional importance (figure 5). It could for example help stabilise the A strand - a region implicated in α sub-unit binding. Amino acids in the A, A' and G β -strands form the interface with the α sub-unit. In $\beta 1$, an aspartic acid residue (D5) separates strands A and A'. This aspartic acid is flanked on either side by glutamic acid residues E 4 and E 8 (Figure. 5). It has previously been shown that the simultaneous replacement of these acidic residues with neutral amino acids formed a protein that was less effective at promoting the fast gating mode of the channel. In $\beta 3$, the entire A/A' face is conserved with one exception: residue D6 of $\beta 1$ is replaced with a proline in $\beta 3$ (figure 4 and 5). Proline tends to break beta-strands, so the gross conformation of the region should be conserved but with less pronounced negative potential. The inventors believe that this difference may suggest that $\beta 3$ could favour the fast gating mode less effectively than $\beta 1$ and thereby inactivate α sub-unit opening more slowly. The inventors thus believe that aminoacids which form the $\beta 3/\alpha$ sub-unit interface would play a crucial role in the modulation of sodium channels.

Interactions with other sub-units of the voltage-gated sodium channel, preferably those involved in covalent or non-covalent interactions with the α sub-unit of the voltage-gated sodium channel. Such polypeptide regions of interactions may be determined by conventional techniques well known to those skilled in the art, such as two hybrid assays as described by Fields and Song, (1989) and also in US Patent N° 5,667,973 as well as in US Patent N°5,283,173 and in Catterall et al. (1998), the technical teachings of these publications being herein incorporated by reference. Other two-hybrid screening assays that may be performed according to the present invention are described by Young et al. (1998), the disclosure of which is also herein incorporated by reference. Other techniques useful to identify biologically relevant

peptide fragments or amino acids involved in the biological activity of the $\beta 3$ sub-units proteins of the invention are described by Patton et al. (1992), the disclosure of which is herein incorporated by reference.

Preferred peptides which fall within the scope of the present invention include
 5 all those which comprise the interface between α sub-unit and the rat or human $\beta 3$ sub-unit. Preferred peptides encoding the β strands A, A' and G of the $\beta 3/\alpha$ sub-unit interface of the rat and human $\beta 3$ protein are SEQ ID N° 22 and are SEQ ID N° 23 (amino acids -24 to 135 of the rat and human $\beta 3$ sequences of figure 4). Other preferred peptides which encode the A and A' β strands are those of SEQ ID N° 17
 10 and SEQ ID N° 18 (amino acids -24 to 15 of the rat and human $\beta 3$ sequences of figure 4), that of SEQ ID N° 19 (amino acids 2 to 10 of the human $\beta 3$ sequences of figure 4), and those of SEQ ID N° 20 and SEQ ID N° 21 (amino acids -7 to 10 of the rat and human $\beta 3$ sequences of figure 4). Other preferred peptides encode the β strand G are SEQ ID N° 24 (amino acids 113 to 122 of the human $\beta 3$ sequences of figure 4) and
 15 SEQ ID N° 30 (amino acids 123 to 135 of the human $\beta 3$ sequences of figure 4).

The model also predicts that amino acids connecting β -strands B'-C, C'-C'', D- E and F-G are orientated away from the cell surface, whereas aminoacids connecting β -strands A'-B, C''-D and E-F are orientated towards the cell surface as
 20 for amino acids connecting C-C', they are orientated approximately parallel to the cell surface. Four N-linked glycosylation sites suggest a significant potential for post-translational modification (figure 5).

Preferred peptides which fall within the scope of the present invention include all those polypeptides which comprise an accessible surface of the $\beta 3$ sub-unit. These
 25 include polypeptides connecting β strands B'-C SEQ ID N° 25 (amino acids 24 to 36 of the human $\beta 3$ sequences of figure 4), that of SEQ ID N° 26 (amino acids 51 to 60 of the human $\beta 3$ sequences of figure 4) connecting β strands C'-C'', that of SEQ ID N° 27 (amino acids 70 to 81 of the human $\beta 3$ sequences of figure 4) connecting β strands D-E, that of SEQ ID N° 28 (amino acids 99 to 112 of the human $\beta 3$ sequences
 30 of figure 4) connecting β strands F-G and that of SEQ ID N° 46 (amino acids 43 to 50) of the human $\beta 3$ sequences of figure 4) connecting β strands C-C'.

In its C-terminal portion the $\beta 3$ polypeptide comprises a hydrophobic region with strong alpha helical propensity (residues 136 to 157, see figure 4) . This region has the properties of a transmembrane domain and is relatively well conserved in $\beta 1$. The cytoplasmic region of $\beta 3$ contains the sequence YLAI. The position and sequence of this motif fits the consensus for an internalization signal recognised by clathrin-coated pits. The inventors believe that the overall structural organisation of this region indicates a possible role for this class of β sub-unit in the movement of sodium channels between cellular compartments. The C-terminal position may therefore represent another target region for the development of therapeutics or detection.

Preferred peptides which also fall within the scope of the present invention include all those which comprise the human and rat $\beta 3$ internalisation signal. These include SEQ ID N° 31 and SEQ ID N° 47 (aminoacids 158 to 191 of the rat and human $\beta 3$ sequences of figure 4), and SEQ ID N° 32 (aminoacids 173 to 179 of the human $\beta 3$ sequence of figure 4).

Further preferred $\beta 3$ sub-unit peptide fragments are those eliciting the production of antibodies that inhibit or block the normal function of the voltage-gated sodium channel. Such inhibition or blocking of function may be measured by the method described in Example 6 and 7 of the present specification.

Other preferred peptide fragments such as defined above have at least ten contiguous amino acids of any one of the amino acid sequences of SEQ ID N°1 or SEQ ID N°2, preferably at least 12 or 15, more preferably at least 20 and most preferably at least 25 consecutive amino acids of any one of the amino acid sequences of SEQ ID N°1 or SEQ ID N°2.

The invention also relates to a $\beta 3$ sub-unit, or a peptide fragment thereof comprising amino acid changes ranging from 1, 2, 3, 4, 5, 10, 20, 25, 30, 35, 40 substitutions, additions or deletions of one amino acid as regards to the $\beta 3$ sub-unit polypeptides of anyone of the amino acid sequences of SEQ ID N°1 or SEQ ID N°2.

In the case of an amino acid substitution in the amino acid sequence of a polypeptide according to the invention, one or several consecutive or non-consecutive amino acids are replaced by "equivalent" amino acids. The expression "equivalent" amino acid is used herein to designate any amino acid that may be substituted for one of

the amino acids belonging to the native protein structure without decreasing the binding properties of the corresponding peptides to the antibodies raised against the $\beta 3$ sub-units polypeptides of the amino acid sequence of SEQ ID Nos 1 and 2. In other words, the "equivalent" amino acids are those which allow the generation or the synthesis of a polypeptide with a modified sequence when compared to the amino acid sequence of the native $\beta 3$ sub-unit protein, said modified polypeptide being able to bind to the antibodies raised against the $\beta 3$ sub-unit protein of the amino acid sequence of SEQ ID Nos 1 and 2 and/or to induce antibodies recognizing the parent polypeptide.

Alternatively, amino acid changes encompassed are those which will not abolish the biological activity of the resulting modified polypeptide. The biological activity of the modified polypeptide may be assessed, for example, as described in examples 6 and 7 of the specification.

These equivalent amino acids may be determined either by their structural homology with the initial amino acids to be replaced, by the similarity of their net charge or of their hydrophobicity, and optionally by the results of the cross-immunogenicity between the parent peptides and their modified counterparts.

The peptides containing one or several "equivalent" amino acids must retain their specificity and affinity properties to the biological targets of the parent protein, as it can be assessed by a ligand binding assay or an ELISA assay.

Examples of amino acids belonging to specific classes include Acidic (Asp, Glu), Basic (Lys, Arg, His), Non-polar (Ala, Val, Leu, Ile, Pro, Met, Phe, Trp) or uncharged Polar (Gly, Ser, Thr, Tyr, Asn, Gln) amino acids.

Preferably, a substitution of an amino acid in a $\beta 3$ sub-unit polypeptide of the invention, or in a peptide fragment thereof, consists in the replacement of an amino acid of a particular class for another amino acid belonging to the same class.

By an equivalent amino acid according to the present invention is also contemplated the replacement of a residue in the L-form by a residue in the D form or the replacement of a Glutamic acid (E) residue by a Pyro-glutamic acid compound. The synthesis of peptides containing at least one residue in the D-form is, for example, described by Koch (1977).

A specific embodiment of a modified peptide of interest according to the present invention, includes, but is not limited to, a peptide molecule which is resistant to proteolysis. This is a peptide in which the -CONH- peptide bond is modified and replaced by a (CH₂NH) reduced bond, a (NHCO) retro inverso bond, a (CH₂-O) methylene-oxy

bond, a (CH₂S) thiomethylene bond, a (CH₂CH₂) carbon bond, a (CO-CH₂) cetomethylene bond, a (CH₂OH-CH₂) hydroxyethylene bond), a (N-N) bound, a E-alcene bond or also a -CH=CH-bond.

5 The invention also encompasses a β 3 sub-unit polypeptide or a fragment thereof in which at least one peptide bond has been modified as described above.

 The polypeptides according to the invention may also be prepared by the conventional methods of chemical synthesis, either in a homogenous solution or in solid phase. As an illustrative embodiment of such chemical polypeptide synthesis techniques, it
10 may be cited the homogenous solution technique described by Houbenweyl (1974) .

 The β 3 sub-unit polypeptide of interest, or a fragment thereof may thus be prepared by chemical synthesis in liquid or solid phase by successive couplings of the different amino acid residues to be incorporated (from the N-terminal end to the C-terminal end in liquid phase, or from the C-terminal end to the N-terminal end in solid phase) wherein the
15 N-terminal ends and the reactive side chains are previously blocked by conventional groups.

 For solid phase synthesis, the technique described by Merrifield (1965a; 1965b) may be used in particular.

 The β 3 sub-unit polypeptides of the invention and their peptide fragments of
20 interest can be used for the preparation of antibodies.

25

AMPLIFICATION OF NUCLEIC ACIDS ENCODING β 3

 Another object of the invention consists of a method for the amplification of a nucleic acid encoding a β 3 sub-unit from a voltage-gated sodium channel, said method
30 comprising the steps of:

 (a) contacting a test sample suspected of containing the target β 3 sub-unit nucleic acid, a fragment or a variant thereof, or a sequence complementary thereto, with an amplification reaction reagent comprising a pair of amplification primers located on either side of the β 3 sub-unit nucleic acid region to be amplified, and

(b) optionally, detecting the amplification products.

In a first preferred embodiment of the above method, the nucleic acid encodes a human or rat $\beta 3$ sub-unit, and more preferably a $\beta 3$ sub-unit of any one of the amino acid sequences of SEQ ID N°1 or SEQ ID N°2.

5 In a second preferred embodiment of the above method, the primers comprise, or consist of, any one of the nucleotide sequences of SEQ ID N°33, SEQ ID N°34 and SEQ ID N° 36 to 41.

In a third preferred embodiment of the above amplification method, the amplification product is detected by hybridization with a labelled probe having a sequence
10 which is complementary to the amplified region.

The invention also concerns a kit for the amplification of a nucleic acid encoding a $\beta 3$ sub-unit from voltage-gated sodium channel, a fragment or a variant thereof, or a complementary sequence thereto in a test sample, wherein said kit comprises:

15 (a) a pair of oligonucleotide primers located on either side of the $\beta 3$ sub-unit nucleic acid region to be amplified;

(b) optionally, the reagents necessary for performing the amplification reaction.

In a first preferred embodiment of the kit described above, the nucleic acid encodes a human or a rat $\beta 3$ sub-unit, and more preferably a $\beta 3$ sub-unit of any one of the
20 aminoacid sequences of SEQ ID N°1 and SEQ ID N°2.

In a second preferred embodiment of the above amplification kit, the amplification product is detected by hybridization with a labelled probe having a sequence which is complementary to the amplified region.

In a third embodiment of the above amplification kit, the amplification primers are
25 selected from the nucleotide sequences of SEQ ID N°33, SEQ ID N°34 and SEQ ID N° 36 to 41.

ANTI-SENSE NUCLEIC ACIDS AND GENE THERAPY

30 A further object of the invention consists of antisense nucleic acids that inhibit or abolish the expression of the $\beta 3$ sub-unit gene according to the invention. Preferred methods using antisense nucleic acid according to the present invention are the procedures described by Sczakiel et al. (1995).

Preferably, the antisense nucleic acids are chosen among the polynucleotides of 15-200bp long that are complementary to the 5' end of a nucleic acid encoding a $\beta 3$ sub-unit protein of the invention, preferably a human or a rat $\beta 3$ sub-unit, more preferably a $\beta 3$ sub-unit of any one of the aminoacid sequences of SEQ ID N°1 and SEQ ID N°2, and most
 5 preferably a nucleic acid selected from the group consisting of the nucleotides sequences of SEQ ID N°3 and SEQ ID N°4 .

Preferred antisense nucleic acids according to the present invention are complementary to a sequence of the human or rat mRNAs of the $\beta 3$ sub-unit that contains the translation initiation codon ATG. However, the antisense nucleic acid can also be
 10 complementary to a sequence in the 3' or 5' untranslated regions.

The antisense nucleic acids of the invention should have a length and a melting temperature sufficient to permit formation of an intracellular duplex having sufficient stability to inhibit the expression of the desired $\beta 3$ sub-unit in the duplex. Strategies for designing antisense nucleic acids suitable for use in gene therapy are disclosed in Green et
 15 al. (1986) and Izant and Weintraub (1984), the disclosures of which are incorporated herein by reference.

Alternative suitable antisense strategies are those described by Rossi et al. (1991), in PCT Applications Nos WO 94/23 026, WO 95/04141, WO 92/18 522 and in the European Patent Application N° EP-0 572 287 A2, incorporated herein by reference.

20 The preferred antisense nucleic acid sequence according to the present invention is the nucleotide sequence of SEQ ID N°35.

For designing antisense nucleic acids according to the present invention, the one skilled in the art may also be guided by the teachings of the publication of Zhiqiang Zhang et al. (1998), the disclosure of which is herein incorporated by reference.

25 Without wishing to be bound by any particular theory, the inventors believe that one way in which modification of sodium channels including a $\beta 3$ sub-unit can alter excitability would be the following mechanism. The decay of the sodium current can be fitted by at least two exponents. The major component of these two currents is significantly shortened by co-expression of the $\beta 3$ sub-units. This is due to the $\beta 3$ sub-unit significantly
 30 shifting the voltage activation curve in a positive direction allowing more rapid repolarization of the membrane potential. Thus an increase in the number of events or transfer of information down the axon occurs. The high density of sodium channels expressed in neurones allows conduction of action potentials to occur over the entire cell

surface. Transient removal of sodium channels from the membrane may afford a reversible method of changing the gain function of a nerve terminal to depolarising input.

Consequently, the inventors believe that inhibition of the expression of the $\beta 3$ sub-unit of the invention, for example via an antisense strategy, may affect the expression and/or the surface expression of the voltage-gated sodium channel of which the $\beta 3$ sub-unit is part, and consequently affect the expression and the biological activity of the whole voltage-gated sodium channel. Such a voltage-gated sodium channel inhibition may be useful for preventing or curing diseases like epilepsy, hyperalgesia and cardiovascular diseases.

Additionally, increasing the inactivation of sodium channels will lead to a damping effect on neuronal excitability.

Moreover, it is suggested that the $\beta 3$ sub-units are tightly bound to the α pore and that trafficking of the complex to the appropriate place requires the $\beta 3$ sub-unit. Thus, a modification, preferably an inhibition, of the $\beta 3$ - α complex may be used to increase sequestration to an intracellular site or reduced trafficking of α and β to terminal membrane reagents. This would reduce excitability since current density during depolarisation would be insufficient to maintain propagation of the action potential.

Furthermore, changing the expression of the $\beta 3$ sub-unit would cause a disruption of sodium channel function in an injured region.

Another object of the invention is the use of the nucleic acids encoding the $\beta 3$ sub-unit or a biologically active peptide fragment thereof in gene therapy, by insertion of the fully functional gene by a vector delivery system that would result in the repair of a damaged area. In order to affect expression of the nucleic acids encoding a $\beta 3$ sub-unit protein of the invention, these nucleic acids must be delivered into a cell. This delivery may be accomplished *in vitro*, as in laboratory procedures for transforming cell lines, or *in vivo* or *ex vivo*, as in the treatment of certain disease states, particularly disease states related to a dysfunction in the voltage-gated sodium channels, and more particularly disease states such as pain, epilepsy, stroke, ischemia, hyperalgesia, cardiovascular disease and Jacobsen Syndrome, Familial Nonchromaffin Paraganglioma, Phenylketonuria due to PTS deficiency and Charcot Marie Tooth disease.

One mechanism is viral infection where the nucleic acid to be expressed is encapsulated in an infectious viral particle. Several non-viral methods for the transfer of polynucleotides into cultured mammalian cells are also contemplated by the present invention, and include, without being limited to, calcium phosphate precipitation: Graham et al., (1973); Chen et al., (1987), DEAE-dextran Gopal: (1985), electroporation: Tur-Kaspa et al., (1986); Potter et al., (1984), direct micro-injection: Harland et al., (1985), and DNA-loaded liposomes: Nicolau et al., (1982); Fraley et al., (1979).

Once the nucleic acid to be expressed has been delivered into the cell, it may be stably integrated into the genome of the recipient cell. This integration may be in the right location and orientation via homologous recombination (gene replacement) or it may be in a random, non specific location. In yet further embodiments, the nucleic acid may be stably maintained in the cell as a separate, episomal segment of DNA. Such nucleic acid segments or episomes encode sequences sufficient to permit maintenance and replication independent of, or in synchronization with the host cell cycle. A suitable gene targeting technique is described in Russel (1998), the disclosure of which is herein incorporated by reference.

One specific embodiment of a method for delivering a nucleic acid to the interior of a cell of a vertebrate *in vivo* comprises the step of introducing a preparation comprising a physiologically acceptable carrier and a naked polynucleotide operatively coding for the polypeptide of interest into the interstitial space of a tissue comprising the cell, whereby the naked polynucleotide is taken up into the interior of the cell and has a physiological effect.

Compositions for use *in vitro* and *in vivo* comprising a naked polynucleotide are described in PCT Application N° WO 90/11 092 (Vical Inc.) as well as in the articles of Tacson et al. (1996) and of Huygen et al., (1996), the disclosures of which are herein incorporated by reference.

Another object of the invention consists of a composition for the *in vivo* production of a $\beta 3$ sub-unit protein or a biologically active peptide fragment thereof. Such a composition may comprise a naked polynucleotide operatively coding for this polypeptide, in solution in a physiologically acceptable carrier, and suitable for introduction into a tissue to cause cells of the tissue to express a functional $\beta 3$ sub-unit protein or a peptide fragment thereof and thus a functional voltage-gated sodium channel.

The amount of vector to be injected to the desired host organism varies according to the site of injection. As an indicative dose, it will be injected between 0.1 and 100 μg of the vector in an animal body, preferably a mammal body, and preferably a human body.

In another embodiment of a gene therapy method of the invention, the nucleic acid that operatively expresses the $\beta 3$ sub-unit protein or a biologically active peptide fragment thereof may be introduced in vitro in a host cell, preferably in a host cell previously harvested from the animal to be treated and more preferably a somatic cell such as a muscle cell or a neuronal cell. In a subsequent step, the cells that have been transformed with the nucleic acid encoding the $\beta 3$ sub-unit protein or its peptide fragment of interest is reintroduced into the animal body in order to deliver the recombinant protein within the body either locally or systemically.

Therefore, the invention is also directed to a composition containing a nucleic acid selected from the group of nucleic acids described therein, in combination with one or several physiologically acceptable carriers, such as those well known from the one skilled in the art.

RECOMBINANT EXPRESSION VECTORS

The present invention also encompasses a family of recombinant vectors comprising any one of the nucleic acids described herein. Thus, the invention further deals with a recombinant vector comprising a nucleic acid selected from the group consisting of :

(a) a purified or isolated nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel, preferably a human or a rat $\beta 3$ sub-unit, and more preferably a polypeptide having at least 80% amino acid identity with a polypeptide selected from the group consisting of the amino acid sequences of SEQ ID N°1 and SEQ ID N°2, or a sequence complementary thereto;

(b) a purified or isolated nucleic acid having at least 90% nucleotide identity with a polynucleotide selected from the group consisting of the nucleotide sequences of SEQ ID N°3 and SEQ ID N°4, or a sequence complementary thereto;

(c) a purified or isolated polynucleotide comprising at least 10 consecutive nucleotides of a nucleic acid described in (a) or (b), or a sequence complementary thereto; and

5 (d) a purified or isolated polynucleotide selected from the group consisting of polynucleotides encoding one of the peptide fragments of $\beta 3$ corresponding to SEQ ID N° 5 to 32 and SEQ ID N°46 and 47.

In a first preferred embodiment a recombinant vector of the invention is used to amplify the inserted polynucleotide derived from the nucleic acid encoding a $\beta 3$ sub-unit of the invention in a suitable host cell, this polynucleotide being amplified every time the
10 recombinant vector replicates.

A second preferred embodiment of the recombinant vectors according to the invention consists of expression vectors comprising a nucleic acid encoding a $\beta 3$ sub-unit of the invention, preferably a nucleic acid encoding a human or a rat $\beta 3$ sub-unit, and more preferably a nucleic acid encoding a polypeptide selected from the group consisting of the
15 amino acid sequences of SEQ ID N°1 and SEQ ID N°2, and most preferably a nucleic acid selected from the group consisting of the nucleotide sequences of SEQ ID N°3 and SEQ ID N°4.

Recombinant expression vectors comprising a nucleic acid encoding the peptide fragments of a $\beta 3$ sub-unit that are specified in the present specification are also part of the
20 invention .

Within certain embodiments, expression vectors can be employed to express the $\beta 3$ sub-unit of the invention or a peptide fragment thereof which can then be purified and for example, be used as a immunogen in order to raise specific antibodies directed against said $\beta 3$ sub-unit protein or a peptide fragment thereof.

25 In another embodiment, the expression vectors are used for constructing transgenic animals and also for gene therapy, notably for antisense therapy.

Expression requires that appropriate signals are provided in the vectors, said signals including various regulatory elements such as enhancers/promoters from both viral and
30 mammalian sources that drive expression of the genes of interest in host cells. The regulatory sequences of the expression vectors of the invention are operably linked to the nucleic acid encoding the $\beta 3$ sub-unit protein of interest or a peptide fragment thereof.

As used herein, the term “operably linked” refers to a linkage of polynucleotide elements in a functional relationship. For instance, a promoter or an enhancer is operably linked to a coding sequence if it affects the transcription of the coding sequence.

More precisely, two DNA molecules (such as a polynucleotide containing a promoter region and a polynucleotide encoding a desired polypeptide or polynucleotide) are said to be “operably linked” if the nature of the linkage between the two polynucleotides does not : (1) result in the introduction of a frame-shift mutation or (2) interfere with the ability of the polynucleotide containing the promoter to direct the transcription of the coding polynucleotide.

Generally, recombinant expression vectors will include origins of replication, selectable markers, permitting transformation of the host cell, and a promoter derived from a highly expressed gene to direct transcription of a downstream structural sequence. The heterologous structural sequence is assembled in an appropriate frame with the translation, initiation and termination sequences, and preferably a leader sequence capable of directing sequences of the translated protein into the periplasmic space or the extra-cellular medium.

In a specific embodiment wherein the vector is adapted for transfecting and expressing desired sequences in mammalian host cells, preferred vectors will comprise an origin of replication from the desired host, a suitable promoter and an enhancer, and also any necessary ribosome binding sites, polyadenylation site, transcriptional termination sequences, and optionally 5'-flanking non-transcribed sequences.

DNA sequences derived from the SV 40 viral genome, for example SV 40 origin, early promoter, enhancer, and polyadenylation sites may be used to provide the required non-transcribed genetic elements.

In another embodiment of a recombinant expression vector of the invention, the 5'-flanking non transcribed sequence may comprise a polynucleotide selected from the group consisting of :

(1) the nucleic acid beginning at the nucleotide in position 1 and ending at the nucleotide in position 362 of the nucleotide sequence of SEQ ID N°3;

(2) the nucleic acid beginning at the nucleotide in position 1 and ending at the nucleotide in position 375 of the nucleotide sequence of SEQ ID N°4.

Additionally, a recombinant expression vector of the invention advantageously also comprises an untranscribed polynucleotide located at the 3'end of the coding sequence

(ORF), this 3'-UTR polynucleotide being useful for stabilizing the corresponding mRNA or for increasing the expression rate of the vector insert if this 3'-UTR harbors regulation signal elements such as enhancer sequences.

A preferred 3'-UTR sequence will be selected from the group consisting of the 3'-
5 UTR sequences contained in the nucleotide sequences of SEQ ID N°3 and SEQ ID N°4.

Thus, a further object of the invention consists of a 3'-UTR nucleic acid selected from the group consisting of :

(1) the nucleic acid beginning at the nucleotide in position 1011 and ending at the nucleotide in position 2220 of the nucleotide sequence of SEQ ID N°3;

10 (2) the nucleic acid beginning at the nucleotide in position 1024 and ending at the nucleotide in position 1261 of the nucleotide sequence of SEQ ID N°4.

Suitable promoter regions used in the expression vectors according to the invention are chosen taking into account the host cell in which the heterologous nucleic acids have to
15 be expressed.

A suitable promoter may be heterologous with respect to the nucleic acid for which it controls the expression, or alternatively can be endogenous to the native polynucleotide containing the coding sequence to be expressed.

Additionally, the promoter is generally heterologous with respect to the
20 recombinant vector sequences within which the construct promoter/coding sequence has been inserted.

Preferred bacterial promoters are the LacI, LacZ, T3 or T7 bacteriophage RNA polymerase promoters, the lambda PR, PL and trp promoters (a EP-0 036 776), the polyhedrin promoter, or the p10 protein promoter from *baculovirus* (kit Novagen; Smith et
25 al., (1983); O'Reilly et al. (1992).

Preferred selectable marker genes contained in the expression recombinant vectors of the invention for selection of transformed host cells are preferably dehydrofolate reductase or neomycin resistance for eukaryotic cell culture, TRP1 for *S. cerevisiae* or
30 tetracycline, rifampicin or ampicillin resistance in *E. coli*, or Levamsaccharase for *Mycobacteria*, this latter marker being a negative selection marker.

Preferred bacterial vectors of the invention are listed hereafter as illustrative but not limitative examples:

pQE70, pQE60, pQE-9 (Quiagen), pD10, phagescript, psiX174, p.Bluescript SK, pNH8A, pNH16A, pNH18A, pNH46A (Stratagene); pKK223-3, pKK233-3, pDR540, 5 pRIT5 (Pharmacia); pWLNEO, pSV2CAT, pOG44, pXT1, pSG (Stratagene); pSVK3, pBPV, pMSG, pSVL (Pharmacia); pQE-30 (QIA express).

Preferred bacteriophage recombinant vectors of the invention are P1 bacteriophage vectors such as described by Sternberg N.L. (1992;1994).

A suitable vector for the expression of a $\beta 3$ sub-unit polypeptide of the invention or 10 a fragment thereof, is a baculovirus vector that can be propagated in insect cells and in insect cell-lines. A specific suitable host vector system is the pVL 1392/1393 *baculovirus* transfer vector (Pharmingen) that is used to transfect the SF9 cell line (ATCC N°CRL 1711) which is derived from *spodoptera frugiperda*.

15 The recombinant expression vectors from the invention may also be derived from an adenovirus such as those described by Feldman and Steig. (1996) or Ohno et al. (1994).

Another preferred recombinant adenovirus according to this specific embodiment of the present invention is the human adenovirus type two or five (Ad 2 or Ad 5) or an adenovirus of animal origin (French Patent Application n°FR 93 05 954).

20 Particularly preferred retrovirus as for the preparation or construction of retroviral *in vitro* or *in vivo* gene delivery vehicles of the present invention include retroviruses selected from the group consisting of Mink-Cell Focus Inducing Virus, murine sarcoma virus, and Ross Sarcoma Virus. Other preferred retroviral vectors are those described in Roth et al. (1996), in PCT Application WO 93/25 234, in PCT Application WO 94/06920, 25 and also in Roux et al. (1989), Julan et al.(1992) and Nada et al. (1991).

Yet, another viral vector system that is contemplated by the invention consist in the adeno associated viruses (AAV) such as those described by Flotte et al. (1992), Samulski et al. (1989) and McLaughlin et al. (1996).

30 Thus, a further object of the invention consists of a recombinant expression vector comprising a nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel or a peptide fragment thereof or a variant thereof, wherein said nucleic acid is operably linked to a promoter sequence.

In a preferred embodiment, this nucleic acid encodes a rat or a human $\beta 3$ sub-unit, and preferably a $\beta 3$ sub-unit of any one of the aminoacid sequences of SEQ ID N°1 and SEQ ID N°2, or a variant or a peptide fragment thereof. Preferred fragments include those of SEQ ID N° 5 to 32. and SEQ ID N° 46 and 47. In a most preferred embodiment, this nucleic acid comprises any one of the nucleotide sequences of SEQ ID N°3 and SEQ ID N°4.

HOST CELLS EXPRESSING $\beta 3$

Host cells that have been transformed or transfected with one of the nucleic acids described herein, or with one of the recombinant vector, particularly recombinant expression vector, described herein are also part of the present invention.

Are included host cells that are transformed (prokaryotic cells) or are transfected (eukaryotic cells) with a recombinant vector such as one of those described above.

Preferred host cells used as recipients for the expression vectors of the invention are the following:

(a) prokaryotic host cells: *Escherichia coli*, strains. (i.e. DH5- α , strain) *Bacillus subtilis*, *Salmonella typhimurium* and strains from species like *Pseudomonas*, *Streptomyces* and *Staphylococcus*;

(b) eukaryotic host cells: HeLa cells (ATCC N°CCL2; N°CCL2.1; N°CCL2.2), Cv 1 cells (ATCC N°CCL70), COS cells (ATCC N°CRL 1650; N°CRL 1651), Sf-9 cells (ATCC N°CRL 1711), C127 cells (ATCC N°CRL-1804), 3T3 cells (ATCC N°CRL-6361), CHO cells (ATCC N°CCL-61), human kidney 293 cells (ATCC N° 45504; N°CRL-1573), BHK (ECACC N°84100 501; N°84111301), PC12 (ATCC N° CRL-1721), NT2, SHSY5Y (ATCC N° CRL-2266), NG108 (ECACC N°88112302) and F11, SK-N-SH (ATCC N° CRL-HTB-11), SK-N-BE(2) (ATCC N° CRL-2271), IMR-32 (ATCC N° CCL-127). A preferred system to which the gene of the invention can be expressed are cell lines such as COS cells, 3T3 cells, HeLa cells, 292 cells and CHO cells. A preferred system for the efficient expression of $\beta 3$ involves the use of CHO cell lines. The gene can be expressed through an endogenous promoter of native CHO, or through an exogenous promoter. Suitable exogenous promoters include such as SV40 and CMV, or perhaps a eucaryotic promoter such as the tetracycline promoter. The preferred promoter being CMV.

In a specific embodiment of the host cells described above, these host cells have also been transfected or transformed with a polynucleotide or a recombinant vector allowing the expression of another voltage-gated sodium channel sub-unit, preferably a sub-unit of the alpha type, and more preferably a sub-unit of the $\alpha 2$ type, such as described in Example 4. Suitable co-expression procedures are also described in Makielski et al. (1996), and by Qu et al. (1995), the disclosure of which is herein incorporated by reference.

The present invention also concerns a method for producing one of the $\beta 3$ sub-unit polypeptides or peptides described herein and especially a polypeptide selected from the group consisting the aminoacid sequences of SEQ ID N°1 or SEQ ID N°2, wherein said method comprises the steps of:

(a) inserting the nucleic acid encoding the desired $\beta 3$ sub-unit polypeptide or peptide fragment thereof in an appropriate vector;

(b) culturing, in an appropriate culture medium, a host cell previously transformed or transfected with the recombinant vector of step (a);

(c) harvesting the culture medium thus conditioned or lyse the host cell, for example by sonication or by an osmotic shock;

(d) separating or purifying, from said culture medium, or from the pellet of the resultant host cell lysate, the thus produced $\beta 3$ sub-unit polypeptide of interest.

In a first preferred embodiment of the above method, the nucleic acid to be inserted in the appropriate vector has previously undergone an amplification reaction, using a pair of primers.

Preferred primers used for such an amplification reaction are the primers of the nucleotide sequences of SEQ ID N°33 and SEQ ID N°34.

In a second preferred embodiment of the above method, the polypeptide thus produced is further characterized, for example by binding onto an immuno-affinity chromatography column on which polyclonal or monoclonal antibodies directed to the $\beta 3$ sub-unit polypeptide or a peptide fragment thereof have previously been immobilised.

Purification of the recombinant $\beta 3$ sub-unit proteins according to the present invention or a peptide fragment thereof may be carried out by passage onto a nickel or copper affinity chromatography column.

In another embodiment, the $\beta 3$ sub-unit polypeptides or peptide fragments thus obtained may be purified, for example, by high performance liquid chromatography, such as reverse phase and/or cationic exchange HPLC, as described by Rougeot et al. (1994).

The reason to prefer this kind of peptide or protein purification is the lack of by-products formed in the elution samples which renders the resultant purified protein or peptide more suitable for therapeutic use.

ANTIBODIES TO $\beta 3$

Polyclonal antibodies may be prepared by immunization of a mammal, especially a mouse or a rabbit, with a polypeptide or peptide according to the invention that is combined with an adjuvant of immunity, and then by purifying the specific antibodies contained in the serum of the immunized animal on an affinity chromatography column on which has previously been immobilized the polypeptide that has been used as the antigen.

Monoclonal antibodies may be prepared from hybridomas according to the technique described by Kohler and Milstein (1975).

The present invention also deals with antibodies produced by the trioma technique and by the human B-cell hybridoma technique, such as described by Kozbor et al. (1983).

Antibodies of the invention also include chimeric single chain Fv antibody fragments (US Patent N° 4,946,778; Martineau et al., (1998), antibody fragments obtained through phage display libraries Ridder et al. (1995) and humanized antibodies (Leger et al., (1997)).

Antibody preparations obtained according to either protocols are useful in quantitative immuno assays for determining the presence of antigen bearing substances in biological samples. The antibodies may also be used in therapeutic compositions aimed to inhibit the biological activity of a $\beta 3$ sub-unit from a voltage-gated sodium channel.

Consequently, the invention is also directed to a method for specifically detecting the presence of a $\beta 3$ sub-unit from a voltage-gated channel in a sample, said method comprising the following steps of :

- (a) bringing into contact a sample to be assayed with an antibody directed against a $\beta 3$ sub-unit protein or to a peptide fragment thereof;
- (b) detecting the antigen-antibody complex formed.

The invention also concerns a kit for detecting *in vitro* the presence of a $\beta 3$ sub-unit polypeptide or a fragment thereof in a sample, wherein said kit comprises an antibody directed against a $\beta 3$ sub-unit polypeptide or a peptide fragment thereof.

5 In a preferred embodiment, the kit further comprises a reagent allowing the detection of the antigen-antibody complexes formed, said reagent carrying optionally a label, or being able to be recognized itself by a labelled reagent, particularly in the case when the above mentioned antibody is not itself labelled.

The antibodies of the present invention are also useful as therapeutic agents capable of blocking the biological activity of brain voltage-gated sodium channel.

10 Thus, another object of the invention consists of a composition containing an antibody as defined herein, in combination with one or several physiologically acceptable carriers, such as those well known from the one skilled in the art.

SCREENING FOR $\beta 3$ LIGANDS

15

The present invention also concerns methods for screening ligand substances or molecules that are able to modulate the biological activity of a voltage-gated sodium channel containing a $\beta 3$ sub-unit of the invention.

20 Production of $\beta 3$ or a fragment thereof

The $\beta 3$ protein or fragments thereof can be prepared using recombinant technology, cell lines or chemical synthesis. Recombinant technology and chemical synthesis of the $\beta 3$ sub-unit or fragments thereof can allow the modification of the gene encoding the $\beta 3$ sub-unit
25 to include such features as recognition tags, cleavage sites and modifications of the $\beta 3$ sub-unit or fragments thereof. For efficient polypeptide production, the recombinant expression system should allow the $\beta 3$ polypeptide to be expressed and transported at the cell surface in a functional form or allow production of $\beta 3$ sub-unit fragments which can be purified. Preferred cell lines are those which allow high levels of expression of $\beta 3$ sub-unit
30 or fragments thereof. Such cell lines include common mammalian cell lines such as Cho cells and Cos cells, etc or more specific neuronal cell lines such as PC12. However, other cell types which are commonly used for recombinant protein production such as insect

cells, amphibian cells such as oocytes, yeast and procaryotic cell lines such as E.coli can also be considered.

The $\beta 3$ sub-unit or fragments thereof can be utilised in a ligand screen either as a purified protein, as a protein chimera such as those described in phage display, as a cell membrane (lipid or detergent) preparation, or in intact cells.

The $\beta 3$ sub-unit or fragment thereof can be utilised in a functional screen format or ligand binding screen format. Examples of both screening formats are provided below.

Functional screening methods

10 A first embodiment of a functional screen comprises of the following steps:

(a) obtaining a recombinant host cell co-expressing a $\beta 3$ sub-unit or a fragment thereof and a functional α sub-unit, preferably an $\alpha 2$ sub-unit of a voltage-gated sodium channel, or a fragment thereof;

15 (b) bringing into contact said recombinant host cell with a substance or molecule to be tested; and

(c) measuring an electrical parameter within the recombinant host cell brought into contact with the substance or molecule to be tested through a voltage clamp technique or measurement of membrane potential by voltage sensitive fluorescent dyes.

20 A first preferred electrical parameter to be measured is the inactivation potential.

A second preferred electrical parameter to be measured is the inactivation time.

A third preferred electrical parameter to be measured is the rate of recovery of the sodium channel.

25 Measurement of membrane potential can be carried out using one of the techniques described in the following references, which describe the utility of voltage sensitive dyes: Biophys-J. 1989 Dec; 56(6): 1053-69, Biochemistry 1989 May 30; 28(11): 4536-9, Chem-Biol. 1997 Apr; 4(4): 269-77, Biophys-J. 1995 Oct; 69(4): 1272-80,. All these publications are incorporated herein by reference.

30 Another embodiment of a functional screening method comprises the following steps:

(a) obtaining a recombinant host cell co-expressing a $\beta 3$ sub-unit or a fragment thereof and a functional α sub-unit, preferably an $\alpha 2$ sub-unit of a voltage-gated sodium channel, or a fragment thereof;

(b) bringing into contact said recombinant host cell with a substance or molecule to be tested; and

(c) measuring the change in sodium flux within the recombinant host cell brought into contact with the substance or molecule to be tested through a sodium flux measuring technique by sodium sensitive dyes such as SBFI.

A first preferred parameter to be measured is the increase in sodium concentration within the cell.

A second preferred parameter to be measured is the decrease in sodium concentration within the cell.

A third preferred parameter to be measured is the rate of recovery of the sodium channel.

Measurement of changes in intracellular sodium concentration can be carried out using one of the techniques described in the following references, which describe the utility sodium sensitive dyes: Witkowski et al Nature 1998, 392, 78, Itoh et al, J. Neuroscience 1998, 71, 112, Mittmann et al, J. Neurophysiol 1997, 78, 1188 and David et al J. Physiol. 1997, 295. All these publications are incorporated herein by reference.

A further embodiment of a functional screening method comprises the following steps:

(a) obtaining a recombinant host cell expressing a functional α sub-unit, preferably an $\alpha 2$ sub-unit of a voltage-gated sodium channel, or a fragment thereof;

(b) bringing into contact said recombinant host cell with a substance or molecule to be tested and a fragment of the $\beta 3$ sub-unit, preferably a fragment of the $\beta 3$ sub-unit from which at least the transmembrane domain has been removed; and

(c) measuring an electrical parameter within the recombinant host cell brought into contact with the substance or molecule to be tested through a voltage clamp technique or measurement of membrane potential by voltage sensitive fluorescent dyes in a similar manner to that described above.

Another embodiment of a functional screening method comprises the following steps:

(a) obtaining a recombinant host cell expressing a functional α sub-unit, preferably an $\alpha 2$ sub-unit of a voltage-gated sodium channel, or a fragment thereof;

(b) bringing into contact said recombinant host cell with a substance or molecule to be tested and a fragment of the $\beta 3$ sub-unit, preferably a fragment of the $\beta 3$ sub-unit from which at least the transmembrane domain has been removed; and

(c) measuring the change in sodium flux within the recombinant host cell brought into contact with the substance or molecule to be tested through a sodium flux measuring technique by sodium sensitive dyes such as SBFI in a similar manner to that described above.

Ligand binding screening method

A typical embodiment of a ligand binding screen comprises of the following steps;

(a) contacting the ligand with the $\beta 3$ sub-unit or a fragment thereof.

The $\beta 3$ polypeptide can be part of an intact cell, membrane preparation or purified polypeptide. The ligand can be a peptide/protein/ antibody or chemical entity. The principal property the ligand must have is that it must recognise and bind to a binding site determined by the $\beta 3$ aminoacid sequence.

Optionally, excess non $\beta 3$ bound ligand can be removed by separation. Separation can take the form of washing /filtering or centrifugation (to pellet the $\beta 3$ protein). In this latter case, the supernatant can then be removed and the $\beta 3$ re-suspended in buffer.

(b) contact the medium containing the ligand and the $\beta 3$ protein or a fragment thereof with a $\beta 3$ substrate and allow binding to occur.

A property of the substrate must be that it is detectable and quantifiable. To achieve this the substrate can be a chromophore or radio, fluorescent, phosphorescent, enzymatically or antibody labelled. If the substrate is not directly detectable it must be amenable to detection and quantification by secondary detection, which may employ the above technologies.

Optionally, unbound substrate can be removed from the mixture as described above.

(c) measurement of substrate binding

Binding of the ligand modifies the interaction of the substrate with the $\beta 3$ binding site and decreases affinity of substrate for the binding site. The difference between the observed

amount of substrate bound relative to the theoretical maximum amount of substrate bound is a reflection of the amount and affinity of ligand bound to the substrate-binding site. The mechanism of detection of substrate is determined by its properties.

Alternatively, the amount of ligand bound to the $\beta 3$ sub-unit or a fragment thereof can be determined by a combination of chromatography and mass spectroscopy.

The amount of ligand bound to the $\beta 3$ sub-unit or a fragment thereof can also be determined by direct measurement of the change in mass upon ligand or substrate binding to $\beta 3$. This could be achieved with technologies such as Biocore (Amersham Pharmacia).

Alternatively, the $\beta 3$ sub-unit or a fragment thereof, the substrate or the ligand can be fluorescently labeled and association of $\beta 3$ with the ligand can be followed by changes in Fluorescence Energy Transfer (FRET).

In a first preferred embodiment of the above methods, substances or molecules of interest are selected among those which induce changes in the activation potential, the inactivation time, or the rate of recovery of the sodium channel.

Preferred molecules or substances are those inducing a decrease in the inactivation potential, and/or a decrease in the rate of inactivation, and/or which decreases the rate of recovery from inactivation, as compared with the same measures performed in the absence of the substance or molecule to be tested.

Molecules that may be assayed according to the method described above comprise, but are not limited to, voltage-dependent channel blockers, tetrodotoxin, lidocaine, phenytoin, carbamazepine, lamotrigine, zonisamide, riluzole, lifarizine, ralitoline, flunarizine, verapamil and carvedilol.

Other substances that may be assayed according to the method described above are molecules from the phenylacetamide family, 6-Iodoamiloride.

Sodium channel openers may also represent good candidate molecules, such as for example carisatrin or BDF-9148 (Beiersdorf).

Therapeutic molecules active on neuropathic pain or migraine may also be used, such as CNS-5161 (Cambridge Neuroscience's).

The invention also concerns a kit for screening substances or molecules capable of modulating the biological activity of voltage-gated sodium channel containing a $\beta 3$ sub-unit.

In a first embodiment, the kit comprises a recombinant host cell co-expressing a $\beta 3$ sub-unit or a fragment thereof and an α sub-unit, preferably an $\alpha 2$ sub-unit, or a fragment thereof.

5 In a second embodiment, the kit comprises a recombinant host cell expressing a functional α sub-unit, preferably an $\alpha 2$ sub-unit, or a fragment thereof, and a fragment of the $\beta 3$ sub-unit, preferably a fragment from which at least the transmembrane domain has been removed.

10 In a third embodiment, the kit comprises the $\beta 3$ sub-unit or a fragment thereof and a suitable $\beta 3$ substrate.

EXAMPLES

EXAMPLE 1: Isolation and cloning of the cDNA encoding the sodium channel $\beta 3$ sub-unit from rat.

15

A variant of the rat pheochromocytoma cell line PC12 that has lost many of its neuroendocrine properties has been studied. Subtractive cloning to isolate cDNAs corresponding to mRNA expressed in normal PC12 cells but missing from the variant were isolated whilst identifying novel neuroendocrine-specific transcripts.

20 Total RNA was prepared from wild-type PC12 and variant cell lines as described by Chomczynski and Saatchi (Chomczynski and Saachi, 1987). Poly A(+) RNA was purified from the total RNA by Oligo dT Cellulose column chromatography (Pharmacia UK) (Aviv and Lader 1972). The yield of mRNA from each cell line was calculated spectrophotometrically before proceeding with subtractive hybridisation using the
25 technique of PCR select (Clontech, USA; Diatchenko et al. 1996). Amplified cDNA fragments derived from genes differentially expressed in the wild-type cells were subcloned into the pTAdv plasmid (Clontech) (Mead et al. 1994) and transformed into *E.coli* strain XLI blue (Bullock et al. 1987) to create a cDNA fragment library. Plasmid
30 minipreps from randomly picked subclones were subjected to automated DNA sequencing and screened through DNA data base searches.

Full length coding sequence of rat $\beta 3$ was isolated by screening a rat brain cDNA library with a partial clone isolated by PCR select. The rat brain cDNA library in

lambdaZap (Short et al. 1988) was plated on *E. coli* strain c600hfl (Huynh et al. 1985) and phage plaques were screened with a 400 bp ³²P-labelled XbaI-SacI. cDNA fragment derived from the PCR select clone. Out of approximately 250,000 plaques, a single positive phage clone was isolated by plasmid rescue in pBluescript km288 plasmid using the *E. coli* XPORT, XLRL system. (Alting-Mees & Short 1994). Both strands of the cDNA insert in km288 were subjected to automated DNA sequencing on both strands using M13 primers and internal sequence-specific primers. The resulting sense nucleic acid sequence is herein referred to as SEQ ID N°3.

10 **EXAMPLE 2: Isolation and cloning of the cDNA encoding the sodium channel β 3 sub-unit from human.**

The human homologue of the novel rat β 3 sub-unit was cloned from a human striatal Lambda ZAP II cDNA library obtained from Stratagene. The entire nucleotide sequence encoding the rat β 3 open reading frame was amplified by PCR. This was performed using 20 mer oligonucleotides:

SEQ ID N°33

5'-ATGCCTGCCTTCAACAGATTGC-3'

(362-383 bp of the rat β 3 sequence) as the forward primer, and

20 SEQ ID N°34

5'-TTATTCCTCCACAGGTACCA-3'

(1007-1026 bp of the rat β 3 sequence) as the reverse primer.

The double stranded PCR product produced was radiolabelled by nick translation with [α ³²P] dATP and [α ³²P] dCTP and used to probe 10⁶ primary plaques bound to nitrocellulose filters in a standard hybridization buffer containing 25% formamide. Single plaques giving rise to positive hybridizations were isolated and insert cDNA sequenced on an ABI 310 DNA analyser. The resulting sense nucleic acid sequence is referred to as SEQ ID N°4.

30 **EXAMPLE 3: Tissue expression by Polymerase Chain Reaction**

Total RNA was prepared from adult rat tissues and PC12 cells, treated with DNAase I to remove genomic contamination, and reverse transcribed using MMLV reverse

transcriptase with anchored oligo dT primer according to the manufacturer's recommendations. Approximately 0.5 and 5 ng of cDNA was separately subjected to PCR amplification using primers specific for rat $\beta 1$ (accession number m91808), rat $\beta 3$ (accession number AJ243395) and, to ensure similar amounts of cDNA were used in each reaction, rat α -tubulin (accession number V01226). The primers used were chosen to correspond to unique sequences in the 3' untranslated region of each β subunit:

$\beta 1$ forward primer (nucleotides 1103-1120) SEQ ID N°36

5' GGTGAAGCAATATGGCCG 3',

reverse primer (nucleotides 1317-1300) SEQ ID N°37

5' AGATGAGGCCCAAGAACC 3',

$\beta 3$ forward primer (nucleotides 1942-1961) SEQ ID N°38

5' GGAAGCTGACTGCCACAGAT 3',

reverse primer (nucleotides 2209-2190) SEQ ID N°39

5' CCTGGGGGACTTTACAAACA 3',

α -tubulin forward primer (nucleotides 298-316) SEQ ID N°40

5' CACTGGTACGTGGGTGAGG 3',

reverse primer (nucleotides 469-448) SEQ ID N° 41

5' TTTGACATGATACAGGGACTGC 3'. PCR was performed as described above

except that amplification reactions included 0.125 μ l Taqstart antibody (CLONETECH). A control amplification lacking cDNA was also included. After amplification the products were separated on 2.5% agarose gels and visualised using ethidium bromide (figure 2).

EXAMPLE 4: In situ hybridization studies of distribution of $\beta 3$ sub-unit.

Whole brains were dissected from adult (150- to 200-g) Wistar rats and snap frozen on dry ice. 10 μ m cryostat sections were thaw mounted onto poly-l-lysine coated slides, fixed with 4% paraformaldehyde in PBS (pH 7.4), dehydrated and stored under ethanol until hybridization. The sequence and location of the anti-sense oligonucleotides used for analysis were as follows:

rat $\beta 1$ (nucleotides 1296-1252) SEQ ID N° 42

5'GCTTGATGGGGTGAAGAGGGGTCGGGACAGGGACAGTAGTGGGC 3',

rat β 3 (nucleotides 389-345) SEQ ID N° 35

5'GGGGAAGCAATCTGTTGAAGGCAGGCATCTTTTCCACCGTAAGCG 3',

rat α IIA (nucleotides 1659-1615) SEQ ID N° 43

5 5'GCAGAATCCAGAGACTTCAGCGGGGCAGGCGGGGATAGGTGTTTTTC 3'.

Oligonucleotides were 3' end-labelled with [³⁵S]dATP (Amersham Pharmacia; 1000 Ci/mmol) by terminal deoxynucleotidyl transferase (Roche Molecular Biochemicals; ref. Ausubel, F.R et al 1989) and used for hybridization at a concentration of 400,000 cpm/100 μ l of hybridization buffer. To confirm the specificity of the hybridizations, 100 fold excess of unlabelled oligonucleotide was added to the hybridization buffer in addition to the radiolabelled probe. Slides were air dried and hybridized overnight at 42°C in 150 μ l buffer containing 50% formamide, 10% dextran sulfate, 50 mM DTT, 1X Denhardt's solution, 0.5 mg/ml denatured salmon sperm DNA and 0.5 mg/ml polyadenylic acid (all Sigma, Poole, U.K.). Sections were washed in 1XSSC at 55°C for 30 minutes, rinsed in 1XSSC, 0.1XSSC dehydrated and apposed to Kodak BiomaxTM MR X-ray film (Amersham Pharmacia) for 10 days.

Sections were observed and photographed using a Polyvar microscope (Reichert-Jung) with camera attached Figure 3.

The sequence depicted in SEQ ID N°35 is the antisense radiolabelled oligonucleotide probe used in the in situ hybridization experiments, unique to target sequence as confirmed by FASTA search (NCBI). This allows the detailed distribution as shown in table 1 to be determined and changes in distribution to be detected. mRNA on adult rat brain sections (emulsion dipped sections and autoradiographs), were rated for relative optical density (ROD): ++++++, +++++, very abundant; +++++, abundant; +++, moderate; ++,+, low; 1/2, just above background; 0, not detectable. n=3-6. VBD - Nucleus of the Vertical limb of the Diagonal Band, VTA – Ventral Tegmental Area, APTD - Anterior Pretectal Nucleus (dorsal part), DpMe – Deep Mesencephalic Nucleus.

Table 1

5		α IIA	β 1	β 3		α IIA	β 1	β 3
	OLFACTORY SYSTEM				THALAMUS			
	Anterior Olfactory	+++	1/2	+++	Reticular Nucleus	0	1/2	0
	Olfactory Tubercle	+++	1/2	+++	Medial Geniculate Nuclei	1/2	++	0
	Piriform Cortex	++++++	++	++++	Ventrolateral Geniculate	++	+	1/2
10	NEOCORTEX				Dorsal Lateral Nuclei	0	+	0
	Layer 2	+++	+	+++	Anteroventral/dorsal Nuclei	++	++	0
	Layer 3	+++	+	+++	Ventral Nuclei	+	1/2	0
	Layer 4/5	++	+++	1/2	Venteropostero Nuclei	0	+	0
15	Layer 6a/6b	+++	0	+	MIDBRAIN			
	Subiculum	++	1/2	++	Superior Colliculus	1/2	0	1/2
	HIPPOCAMPUS				APTD	++	1/2	1/2
	CA1	++++	+++	+++++	DpMe	1/2	0	0
20	CA2	+++++	+++	+++++	Oculomotor Nucleus	+	0	1/2
	CA3	+++++	+++++	+++++	Red Nucleus	+	1/2	0
	Dentate Gyrus	+++++	+++	+++++	Interpeduncular Nucleus	+	0	0
	Hilus Dentate Gyrus	++	+	++	Inferior Colliculus		1/2	1/2
	Indusium Gresium	++++	0	+	Central Grey		0	1/2
25	Tenia Tecta	++++	+	+++++	BRAINSTEM			
	BASAL GANGLIA				Pontine Nucleus	0	+++	0
	Caudate Putamen	+	0	+++	Trapezoid Body	+	++	0
	Globus Palidus	0	0	0	Inferior Olivary Nucleus	0	+	1/2
30	Nucleus Accumbens	+	0	++	Locus Ceruleus	+	0	+
	VBD	1/2	0	1/2	Raphe Nuclei	0	1/2	0
	Habenula	++++	0	+++++	Pontine Reticular Formation	0	1/2	0
	Amygdala	+	0	++	Motor Trigeminal Nucleus	1//2	+	0
	Hypothalamus	1/2	0	1/2	Me5 Cells	+	0	0
35	Preoptic Area	1/2	0	1/2	Facial Nuclei	0	1/2	0
	Supraoptic	+	0	1/2	Vestibular Nuclei	0	1/2	0
	Mammillary Body	+	0	+	Solitary Nucleus	0	1/2	0
	Substantia Nigra	1/2	0	1/2	Cuneate Nucleus	0	+++	0
	VTA		+	0	Dorsal Tegmental Nucleus	+	1/2	+
40	CEREBELLUM				Lateral Parabrachial Nucleus	+	0	0
	Granular Cell Layer	+++++	+++++	0	Hypoglosseal Nucleus	1/2	0	0
	Purkinje Cell Layer	+++	+++++	0	Spinal Trigeminal Nucleus	1/2	1/2	0
	Molecular Cell Layer	0	0	0	SEPTUM			
45					Bed Nucleus Stria Terminalis	+	0	+
					Lateral Septal Nucleus	+	0	+

EXAMPLE 5: Sequence comparison and three dimensional modelling of the extracellular domain of the $\beta 3$ sub unit.

Amino acid sequences of rat and human $\beta 3$ were aligned with the sequences of
 5 rat $\beta 1$ (SWISS-PROT Q00954) (Isom, L.L 1992); and the extracellular domain of rat
 myelin P_0 (SWISS-PROT P06907) (Lemke G. & Axel, R. 1985). The multiple
 alignment was generated with CLUSTALW (Higgins, D.G 1996) and formatted with
 ALSCRIPT (Barton, G.J. 1993) (Figure 4). The sequence numbering is based on rat
 $\beta 3$, starting from the predicted N-terminus of the mature protein. Amino acid
 10 identities with rat $\beta 3$ are indicated by shading. The putative signal sequence and
 internalization signal are underlined and labelled. The putative transmembrane domain
 (TM) is boxed. Three negatively charged amino acid residues, previously identified as
 part of the α -sub-unit binding site of $\beta 1$, are boxed. Invariant residues and the position
 of amino acids characteristic of the IgV domain are indicated beneath the sequence of
 15 myelin P_0 : h, hydrophobic; l, aliphatic; %, neutral or hydrophobic; +, base; =,
 hydrophobic or Ser, Thr; #, Gly or Ala (rarely Asp) (17). Secondary structure elements
 in the crystal structure of myelin P_0 (Shapiro, L 1996) used to model $\beta 3$ are also
 shown: arrow, beta-strand; cylinder, alpha- or 3_{10} -helix.

The model for the three-dimensional structure of the mature extracellular
 20 domain (residues 1-123) of rat $\beta 3$. The model was generated with MODELLER (Sali,
 A. & Blundell, T.L. 1993) using the crystal structure of rat myelin P_0 (PDB 1neu)
 (Shapiro, L 1996) as a template and the alignment shown in (Figure 5). Figure 5 was
 drawn with MOLSCRIPT (Kraulis, P.J. 1991) and RASTER3D (Merrit, E. & Murphy,
 M. 1994). The side chains of acidic residues in the putative α subunit binding site are
 25 shown in ball-and-stick representation. Two predicted disulfide bonds are labelled in
 black. N-linked glycosylation sites (NXT and NXS) (Kornfeld, R. & Kornfeld, S.
 1985) are indicated by asterisks. The potential glycosylation site on the F strand (N97)
 points away from the viewer and is below the plane of the paper.

Note: In this model the B strand is broken into two parts labelled B and B' respectively.
 30 This secondary structure assignment is based on the definition of Kabsch & Sander (1983)
 for the PDB entry 1neu and is different from the assignment described in the original paper
 (Shapiro, L 1996).

EXAMPLE 6: Functional expression of β_3 sub-unit in a recombinant system.

Capped cRNA for rat brain type IIA α sub-unit and rat β_3 sub-unit were transcribed *in vitro* from transcribed cDNAs (Promega, Southampton, UK). pBSK β_3 was linearized with NotI and transcribed with T7 polymerase, while ZEMRVSP6-2580 α_2 was linearized with ClaI and transcribed with SP6 polymerase. Xenopus laevis were anaesthetised by immersion in 0.3% (w/v) 3-amino benzoic acid (Sigma, Poole, U K) and Ovarian lobes were removed. Oocytes were dissociated using 0.3% (w/v) collagenase (Sigma, Poole, U K) in Ca^{2+} -free solution (82.5 mM NaCl, 2.5 mM KCl, 1 mM MgCl_2 , 5 mM, Hepes, pH 7.6). Prepared oocytes were microinjected with 50 nl of cRNAs dissolved in water. Oocytes were incubated at 18°C in ND96 (96 mM NaCl; 2mM KCl, 1.8 mM CaCl_2 , 1 mM MgCl_2 , 5 mM Hepes, pH 7.6). Two-electrode voltage clamp recordings were performed 3-6 days after microinjection of cRNAs using a Gene Clamp 500 amplifier (Axon Instruments, CA, USA) interfaced to a Digidata 1200 A/D board with Clampex software (v6, Axon Instruments, CA, USA). Oocytes were continually perfused with ND96, Microelectrodes filled with 3 M KCl had resistances between 0.5-2 M Ω . Currents were sampled at 10 kHz and filtered at 2 kHz. Data were analyzed using Clampfit (v6, Axon Instruments, CA, USA) and Prism (v2, Graphpad Software, CA, USA).

Inward Na^+ currents were induced by applying 5 mV depolarizing pulses from a holding potential of -100 mV, from -80 mV to + 30 mV. Na^+ currents recorded from oocytes expressing IIA α subunit alone. Inactivation at -10 mV was best-fitted with a double exponential function, where $\tau_1 = 2 \pm 0.3$ ms and $\tau_2 = 12.7 \pm 2.4$ ms ($n = 4$). **b.** Na^+ currents recorded from oocytes coexpressing IIA α and β_1 subunits. Inactivation was best-fitted with a double exponential function, where $\tau_1 = 1.3 \pm 0.3$ ms and $\tau_2 = 22.7 \pm 7.7$ ms at -10 mV ($n = 4$). **c.** Na^+ currents recorded from oocytes coexpressing IIA α and the β_3 subunits. Inactivation was best-fitted with a double exponential function, where $\tau_1 = 1 \pm 0.1$ ms and $\tau_2 = 23.8 \pm 6.3$ ms at -10 mV ($n = 4$).

Comparison of steady-state inactivation curves for Na^+ currents recorded from oocytes coexpressing α_2 and β_3 with oocytes expressing α_2 alone. Data were fitted to Boltzmann function, $g/g_{\max} = J / \{1 + \exp[(V-V_{1/2})/k]\}$, where $V_{1/2}$ is the midpoint and k is

the slope factor. For $\alpha 2 + \beta 3$, $V_{1/2} = -49.4$ mV, $k = 10.1$ mV, while for $\alpha 2$, $V_{1/2} = -41.3$ mV, $k = 9.1$ mV. Co-expression of $\beta 3$ with $\alpha 2$ causes a hyperpolarizing shift in the steady-state inactivation curve.

Comparison of rate of recovery from inactivation for Na^+ currents recorded from oocytes co-expressing $\alpha 2$ and $\beta 3$ with oocytes expressing $\alpha 2$ alone. Data were fitted with double exponential functions. For $\alpha 2 + \beta 3$, $\tau_1 = 1.9$ ms, $\tau_2 = 198$ ms while for $\alpha 2$, $\tau_1 = 3.8$ ms, $\tau_2 = 264$ ms. Co-expression of $\beta 3$ with $\alpha 2$ increases the rate of recovery from inactivation.

The same procedures were used to express the human form of $\beta 3$ and to measure the effects of co-expression with the type IIA α . For type IIA α alone Inactivation was best-fitted with a double exponential function, where $\tau_1 = 1.78 \pm 0.4$ ms and $\tau_2 = 13 \pm 1.25$ (n = 4). For type IIA α and human $\beta 3$, inactivation was best-fitted with a double exponential function, where $\tau_1 = 1 \pm 0.1$ ms and $\tau_2 = 9.1 \pm 1.4$ ms. $\tau_1/(\tau_1 + \tau_2) = 0.72 \pm 0.03$.

This methodology is a technology for detecting changes in the function of the sodium channel complex as shown in figure 6.

EXAMPLE 7: Functional expression of $\beta 3$ sub-unit in a recombinant system.

Capped cRNA for rat brain αIIA subunit and rat $\beta 1$ - or $\beta 3$ -subunits were transcribed *in vitro* from linearized cDNAs (Promega). *Xenopus laevis* were anaesthetised by immersion in 0.3% (w/v) 3-amino benzoic acid (Sigma) and ovarian lobes were removed. Oocytes were dissociated using 0.3% (w/v) collagenase (Sigma) in Ca^{2+} -free solution (82.5 mM NaCl, 2.5 mM KCl, 1 mM MgCl_2 , 5 mM Hepes, pH 7.6). Prepared oocytes were microinjected with 50 nl of cRNAs (0.2-1ng α cRNA, 10ng of $\beta 1$ or $\beta 3$ cRNA) dissolved in water. The cRNA concentration was estimated by UV spectrophotometry and agarose gel electrophoresis. Oocytes were incubated at 18°C in ND96 (96 mM NaCl, 2 mM KCl, 1.8 mM CaCl_2 , 1 mM MgCl_2 , 5 mM Hepes, pH 7.6). Two-electrode voltage clamp recordings were performed 3-6 days after microinjection of cRNAs using a GeneClamp 500 amplifier (Axon Instruments, Foster City, CA, USA) interfaced to a Digidata 1200 A/D board with CLAMPEX software (version 6, Axon Instruments). Oocytes were continually perfused with ND96. Microelectrodes filled with 3 M KCl had resistances between 0.5-2 M Ω . Currents were sampled at 10 kHz and filtered at 2 kHz. Data were analysed using CLAMPFIT

(version 6, Axon Instruments) and ORIGIN (version 5, Microcal Software, Northampton, MA). Exponential functions were fitted to data using the simplex fitting algorithm in CLAMPFIT.

(a) Na^+ currents recorded from oocytes expressing rat αIIA , rat αIIA + rat $\beta 1$ and rat αIIA + rat $\beta 3$ subunits. Inward Na^+ currents were evoked by applying depolarising pulses in 5 mV increments from a holding potential of -100 mV, from -80 mV to +30 mV. Duration of the pulses was 50 ms.

(b) Normalized Na^+ currents from oocytes expressing rat αIIA , rat αIIA + rat $\beta 1$ and rat αIIA + rat $\beta 3$ subunits. Currents evoked by a voltage pulse to -10 mV were normalized to peak amplitudes. Inactivation of Na^+ currents at -10 mV were fitted with a double exponential decay:

$I = A1 \exp(-t/\tau 1) + A2 \exp(-t/\tau 2) + C$, Where A1 and A2 are the relative amplitudes of fast and slow components $\tau 1$ and $\tau 2$ are the inactivation time constants and C is the steady-state asymptote. See table 2 for fit parameters.

(c). Recovery from inactivation of αIIA co-expressed with $\beta 1$ or $\beta 3$.

The recovery pulse protocol was a 1 s inactivating pulse to -10 mV followed by conditioning pulses to -100 mV for increasing periods of time (from 1-1000 ms), followed by a test pulse to -10 mV. Points were sampled every 1 ms from 1 to 20 ms, then every 50 ms from 50 to 1000 ms. Peak current amplitudes measured during the test pulse were normalized to the peak currents evoked during the inactivating pulse and were plotted as function of conditioning pulse duration. αIIA , αIIA + $\beta 1$, αIIA + $\beta 3$: Data were fitted with a double exponential equation: $I = 1 - [A1 \exp(-t/\tau 1) + A2 \exp(-t/\tau 2)]$ where A1 and A2 are the relative amplitudes of recovery and $\tau 1$ and $\tau 2$ are the recovery time constants. See table 2 for fit parameters.

(d). Voltage-dependence of inactivation of αIIA co-expressed with $\beta 1$ or $\beta 3$. A two step protocol was applied using a conditioning pulse of 500 ms duration from -110 mV to +10 mV in 5 mV increments, followed by a test pulse to -10 mV. Peak current amplitudes evoked by the test pulse were normalized to the maximum peak current amplitude and plotted as a function of the conditioning pulse potential. Data were fitted with a two-state Boltzman equation: $g = 1/[1 + \exp\{(V - V_{1/2})/k\}]$, where g is conductance, $V_{1/2}$ is the voltage of half-maximal inactivation and k is the slope factor. See table 2 for fit parameters.

<u>Inactivation timecourse[#]</u>				<u>Recovery from inactivation[#]</u>				<u>Voltage-dependence of inactivation^s</u>			
<u>Subunit</u>	τ_1 (ms)	τ_2 (ms)	<u>Percentage</u> in fast mode	<u>n</u>	τ_1 (ms)	τ_2 (ms)	<u>Percentage</u> in fast mode	<u>n</u>	$V_{1/2}$ (mV)	k (mV)	<u>n</u>
α_{IIA}	2.4 ± 0.3	10.9 ± 1.3	46 ± 4	8	3.9 ± 0.2	446 ± 9	38 ± 0.4	5	-45.1 ± 0.3	9.8 ± 0.2	4
$\alpha_{IIA} + \beta_1$	1.4 ± 0.2	24.7 ± 4.3	95 ± 1	5	2 ± 0.1	148 ± 19	84 ± 0.4	5	-49.1 ± 0.3	5.9 ± 0.2	4
$\alpha_{IIA} + \beta_3$	1.5 ± 0.2	24.7 ± 4.3	85 ± 1	6	4.1 ± 0.2	170 ± 17	73 ± 1.2	5	-49.3 ± 0.2	6.1 ± 0.1	4

Table 2

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Ser Ile Phe His Tyr Ala Lys Gly Gln Pro Tyr Ile Asp Glu Val Gly
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Tyr Leu Ala Ile Pro Ser Glu Asn Lys Glu Asn Ser Val Val Pro Val

20

25

30

Glu Glu

5

Claims:

1. A purified or isolated nucleic acid encoding a $\beta 3$ sub-unit from a voltage-gated sodium channel, or a sequence complementary thereto.

2. The nucleic acid of claim 1, which encodes a $\beta 3$ sub-unit from the voltage-gated sodium channel present in the rat brain, or a sequence complementary thereto.

3. The nucleic acid of claim 1, which encodes the $\beta 3$ sub-unit from the voltage-gated sodium channel present in the human brain, or a sequence complementary thereto.

4. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid encodes a polypeptide having at least 80% amino acid identity with the $\beta 3$ sub-unit polypeptide of the amino acid sequence of SEQ ID NO 1, or with a peptide fragment thereof, or a sequence complementary thereto.

5. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid encodes a polypeptide having at least 80% amino acid identity with the $\beta 3$ sub-unit polypeptide of the amino acid sequence of SEQ ID NO 2, or a sequence complementary thereto.

6. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid has at least 90% nucleotide identity with the nucleotide sequence of SEQ ID NO 3, or a sequence complementary thereto.

7. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid comprises a polynucleotide having at least 90% nucleotide identity with the sequence beginning at the nucleotide located in position 363 and ending at the nucleotide located in position 1010 of the nucleotide sequence of SEQ ID N°3.

8. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid comprises a sequence beginning at the nucleotide located in position 1 and ending at the nucleotide located in position 362 of the nucleotide sequence of SEQ ID N°3.

9. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid comprises a sequence beginning at the nucleotide located in position 1011 and ending at the nucleotide located in position 2220 of the nucleotide sequence of SEQ ID N°3.

10. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid has at least 90% nucleotide identity with the nucleotide sequence of SEQ ID NO 4, or a sequence complementary thereto.

11. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid comprises a polynucleotide having at least 90% nucleotide identity with the sequence

beginning at the nucleotide located in position 376 and ending at the nucleotide in position 1023 of the nucleotide sequence of SEQ ID N°4.

12. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid comprises a sequence beginning at the nucleotide located in position 1 and ending at the nucleotide located in position 375 of the nucleotide sequence of SEQ ID N°4.

13. A purified or isolated nucleic acid according to claim 1, wherein said nucleic acid comprises a sequence beginning at the nucleotide located in position 1024 and ending at the nucleotide located in position 1261 of the nucleotide sequence of SEQ ID N°4.

14. A purified or isolated polynucleotide comprising at least 10 consecutive nucleotides of a nucleic acid encoding a β 3 sub-unit of a voltage-gated sodium channel.

15. A purified or isolated nucleic acid according to claim 14, wherein said nucleic acid comprises at least 10 consecutive nucleotides of the nucleotide sequence of SEQ ID NO 3, or a sequence complementary thereto.

16. A purified or isolated nucleic acid according to claim 14, wherein said nucleic acid comprises at least 10 consecutive nucleotides of the nucleotide sequence of SEQ ID NO 4, or a sequence complementary thereto.

17. A purified or isolated nucleic acid according to claim 14, wherein said nucleic acid is selected from the group consisting of SEQ ID N° 35 to 43 or a polynucleotide encoding a peptide of SEQ ID N° 5 to 32, SEQ ID N° 46 or SEQ ID N° 47.

18. A method for the amplification of a β 3 subunit nucleic acid, said method comprising the steps of :

a) contacting a test sample suspected of containing the targeted β 3 subunit nucleic acid or a fragment thereof with amplification reaction reagents comprising a pair of amplification primers which can hybridize to a nucleic acid according to any one claims 1 to 17, and

b) optionally, detecting the amplification products.

19. The method according to claim 18, wherein the amplification primers are respectively the nucleotide sequences of SEQ ID Nos 33 and 35.

20. A kit for the amplification of a β 3 subunit nucleotide sequence, wherein said kit comprises :

a) a pair of amplification primers which can hybridize to a β 3 subunit nucleic acid according to any one of claims 1 to 17, and

b) optionally, the reagents necessary for performing the amplification reaction.

21. A method for detecting the presence of polynucleotide comprising a nucleic acid according to any one of claims 1 to 17 in a sample, wherein said method comprises the steps of :

a) bringing into contact a nucleic acid probe or a plurality of nucleic acid probes which can hybridize, under stringent hybridization conditions, to a nucleotide sequence included in a nucleic acid according to any one of claims 1 to 17, and the sample to be assayed;

b) detecting the hybrid complex formed between the probe or the plurality of probes and the nucleic acid in the sample.

22. The method of claim 21, wherein the nucleic acid probe or the plurality of nucleic acid probes are immobilized on a substrate.

23. The method of claim 21, wherein the nucleic acid probe or the plurality of nucleic acid probes is labeled with a detectable molecule.

24. A kit for detecting the presence of a polynucleotide comprising a nucleic acid according to any one of claims 1 to 17, wherein said kit comprises :

a) a nucleic acid probe or a plurality of nucleic acid probes which can hybridize, under stringent hybridization conditions, to a nucleotide sequence included in a nucleic acid according to any one of claims 1 to 16;

b) optionally, the reagents necessary to perform the hybridization reaction.

25. The kit of claim 24, wherein the nucleic acid probe or the plurality of nucleic acid probes are immobilized on a substrate.

26. The kit of claim 24, wherein the nucleic acid probe or the plurality of nucleic acid probes are labeled with a detectable molecule.

27. A recombinant vector comprising a nucleic acid according to any one of claims 1 to 17.

28. A recombinant host cell comprising a nucleic acid according to any one of claims 1 to 17.

29. A method for producing a polypeptide encoded by a nucleic acid according to any one of claims 1 to 7, 10, 11 and, 14 to 17, wherein said method comprises the following steps of :

a) culturing, in an appropriate culture medium, a host cell previously transformed or transfected with a polynucleotide according to any one of claims 1 to 7, 10, 11 and, 14 to 17;

b) harvesting the culture medium thus conditioned or lyse the host cell, for example by sonication or by osmotic shock; and

c) separating or purifying, from said culture medium, or from the pellet of the resulting cell lysate, the thus produced polypeptide of interest.

5 30. A purified or isolated polypeptide comprising the amino acid sequence of the β 3 sub-unit from a voltage-gated sodium channel, or a peptide fragment thereof.

31. The polypeptide of claim 30, which comprises the amino acid sequence of the β 3 sub-unit from a voltage-gated sodium channel present in the rat brain, or a peptide fragment thereof.

10 32. The polypeptide of claim 30, which comprises the amino acid sequence of the β 3 sub-unit from a voltage-gated sodium channel present in the human brain, or a peptide fragment thereof.

33. A purified or isolated polypeptide comprising an amino acid sequence having at least 90% amino acid identity with the amino acid sequence of SEQ ID NO 1, or a peptide
15 fragment thereof.

34. A purified or isolated polypeptide comprising an amino acid sequence having at least 90% amino acid identity with the amino acid sequence of SEQ ID NO 2, or a peptide fragment thereof.

35. A purified or isolated polypeptide encoded by a nucleic acid of any one of
20 claims 1 to 7, 10, 11, 14 to 17.

36. A purified or isolated polypeptide selected from the group consisting of the polypeptides of SEQ ID N° 5 to 32 and SEQ ID 46 and 47.

37. A method for screening ligand substances or molecules that are able to modulate the biological activity of a voltage-gated sodium channel containing a β 3 sub-unit, said method comprising:
25

(a) obtaining a recombinant host cell co-expressing a β 3 sub-unit or a fragment thereof and a functional α sub-unit, preferably an α 2 sub-unit of a voltage-gated sodium channel, or a fragment thereof;

(b) bringing into contact said recombinant host cell with a substance or molecule to
30 be tested; and

(c) measuring an electrical parameter within the recombinant host cell brought into contact with the substance or molecule to be tested through a voltage clamp technique or measurement of membrane potential by voltage sensitive fluorescent dyes.

38. A method for screening ligand substances or molecules that are able to modulate the biological activity of a voltage-gated sodium channel containing a $\beta 3$ sub-unit, said method comprising:

(a) contacting the ligand with the $\beta 3$ sub-unit or a fragment thereof;

5 (b) contacting the medium containing the ligand and the $\beta 3$ protein or a fragment thereof with a $\beta 3$ substrate and allowing the possible binding of the substrate to the $\beta 3$ protein or a fragment thereof to occur; and

(c) measuring the eventual binding of the substrate to the $\beta 3$ protein or a fragment thereof.

ABSTRACT OF DISCLOSURE

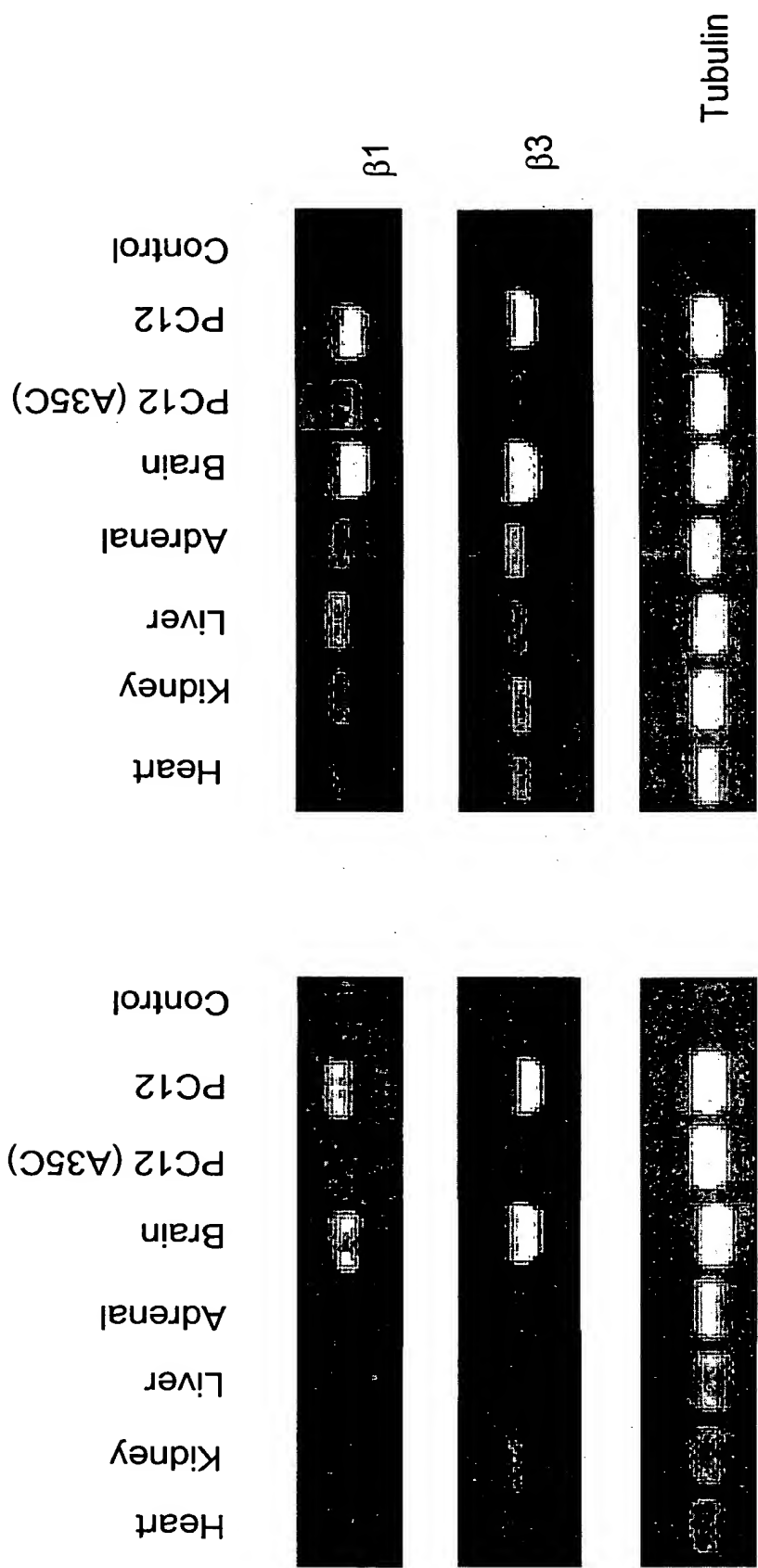
A novel family of beta sub-unit proteins from a voltage-gated sodium channel, nucleic acids encoding them and therapeutic or diagnostic uses thereof.

The present invention relates to a novel family of beta sub-unit proteins from a voltage-gated sodium channel, and particularly the human and the rat beta sub-units which have been collectively identified as $\beta 3$, in view of their close structural relationship.

The invention also deals with the use of the $\beta 3$ sub-unit polypeptide or a fragment thereof as well as of the nucleic acids encoding same for therapeutic, diagnostic and screening purposes.

Figure 1

human beta 3 ORF	(1)	ATGCCTGCCTTCAATAGATTGTTTCCCCTGGCTTCTCTCGTGCTTATCTA	
Rat Beta 3 ORF	(1)	ATGCCTGCCTTCAACAGATTGCTTCCCCTAGCTTCTCTAGTGCTCATCTA	
Consensus	(1)	ATGCCTGCCTTCAA AGATTG TTCCCCT GCTTCTCT GTGCT ATCTA	100
human beta 3 ORF	(51)	CTGGGTCAGTGTCTGCTTCCCTGTGTGTGTGGAAGTGCCCTCGGAGACGG	
Rat Beta 3 ORF	(51)	CTGGGTCAGAGTCTGCTTCCCTGTGTGTGTGGAAGTGCCCTCGGAGACAG	
Consensus	(51)	CTGGGTCAG GTCTGCTTCCCTGTGTGTGTGGAAGTGCCCTCGGAGAC G	150
human beta 3 ORF	(101)	AGGCCGTGCAGGGCAACCCCATGAAGCTGCGCTGCATCTCCTGCATGAAG	
Rat Beta 3 ORF	(101)	AAGCGGTGCAGGGCAATCCCATGAAGCTGAGGTGCATCTCCTGCATGAAG	
Consensus	(101)	A GC GTGCAGGGCAA CCCATGAAGCTG G TGCATCTCCTGCATGAAG	200
human beta 3 ORF	(151)	AGAGAGGAGGTGGAGGCCACCACGGTGGTGGGAATGGTTCTACAGGCCCGA	
Rat Beta 3 ORF	(151)	AGGGAGGAGGTGGAGGCCACCACGTGGTGGAGTGGTTCTACAGGCCCTGA	
Consensus	(151)	AG GAGGAGGTGGAGGCCACCAC GTGGTGGGA TGGTTCTACAGGCC GA	250
human beta 3 ORF	(201)	GGGCGGTAAAGATTTCTTATTTACGAGTATCGGAATGGCCACCAGGAGG	
Rat Beta 3 ORF	(201)	GGGCGGTAAAGATTTCTTATATATGAGTATCGGAATGGCCACCAGGAAG	
Consensus	(201)	GGGCGGTAAAGATTTCTTAT TA GAGTATCGGAATGGCCACCAGGA G	300
human beta 3 ORF	(251)	TGGAGAGCCCCTTTCAGGGGCGCCTGCAGTGGGAATGGCAGCAAGGACCTG	
Rat Beta 3 ORF	(251)	TGGAGAGCCCCTTCCAAGGCCGTCTGCAGTGGGAATGGGAGCAAAGACCTG	
Consensus	(251)	TGGAGAGCCCCTT CA GG CG CTGCAGTGGGAATGG AGCAA GACCTG	350
human beta 3 ORF	(301)	CAGGACGTGTCCATCACTGTGCTCAACGTCACTCTGAACGACTCTGGCCT	
Rat Beta 3 ORF	(301)	CAGGACGTATCCATCACTGTACTCAATGTCACTTTGAATGACTCTGGCCT	
Consensus	(301)	CAGGACGT TCCATCACTGT CTCAA GTCACT TGAA GACTCTGGCCT	400
human beta 3 ORF	(351)	CTACACCTGCAATGTGTCCCGGGAGTTTGAGTTTGAGGCGCATCGGCCCT	
Rat Beta 3 ORF	(351)	CTACACATGCAATGTGTGCCAGGGAGTTCGAATTCGAGGCACACAGCCCTT	
Consensus	(351)	CTACAC TGCAATGTGTCC GGGAGTT GA TT GAGGC CA GGCC T	450
human beta 3 ORF	(401)	TTGTGAAGACGACGCGGCTGATCCCCCTAAGAGTCACCGAGGAGGCTGGA	
Rat Beta 3 ORF	(401)	TTGTGAAGACCACGAGACTGATACCTTTGCGAGTCACTGAAGAGGCGGGA	
Consensus	(401)	TTGTGAAGAC ACG G CTGAT CC T GAGTCAC GA GAGGC GGA	500
human beta 3 ORF	(451)	GAGGACTTCACCTCTGTGGTCTCAGAAATCATGATGTACATCCTTCTGGT	
Rat Beta 3 ORF	(451)	GAAGACTTCACCTCCGTGGTCTCGGAAATCATGATGTACATCCTCCTGGT	
Consensus	(451)	GA GACTTCACCTC GTGGTCTC GAAATCATGATGTACATCCT CTGGT	550
human beta 3 ORF	(501)	CTTCCTCACCTGTGGCTGCTCATCGAGATGATATATTGCTACAGAAAGG	
Rat Beta 3 ORF	(501)	CTTCCTCACCTGTGGCTGTTTATTGAGATGATCTATTGCTACAGAAAGG	
Consensus	(501)	CTTCCTCACC TGTGGCTG T AT GAGATGAT TATTGCTACAGAAAGG	600
human beta 3 ORF	(551)	TCTCAAAGCCGAAGAGGCAGCCCAAGAAAACGCGTCTGACTACCTTGCC	
Rat Beta 3 ORF	(551)	TCTCTAAGGCCGAAGAGGCAGCACAGGAAAATGCGTCTGACTACCTTGCT	
Consensus	(551)	TCTC AA GCCGAAGAGGCAGC CA GAAAA GCGTCTGACTACCTTGC	648
human beta 3 ORF	(601)	ATCCCATCTGAGAACAAGGAGAACTCTGCGGTACCAGTGGAGGAATAG	
Rat Beta 3 ORF	(601)	ATCCCTTCAGAGAACAAGGAGAACTCTGTGGTACCTGTGGAGGAATAA	
Consensus	(601)	ATCCC TC GAGAACAAGGAGAACTCTG GGTACC GTGGAGGAATA	

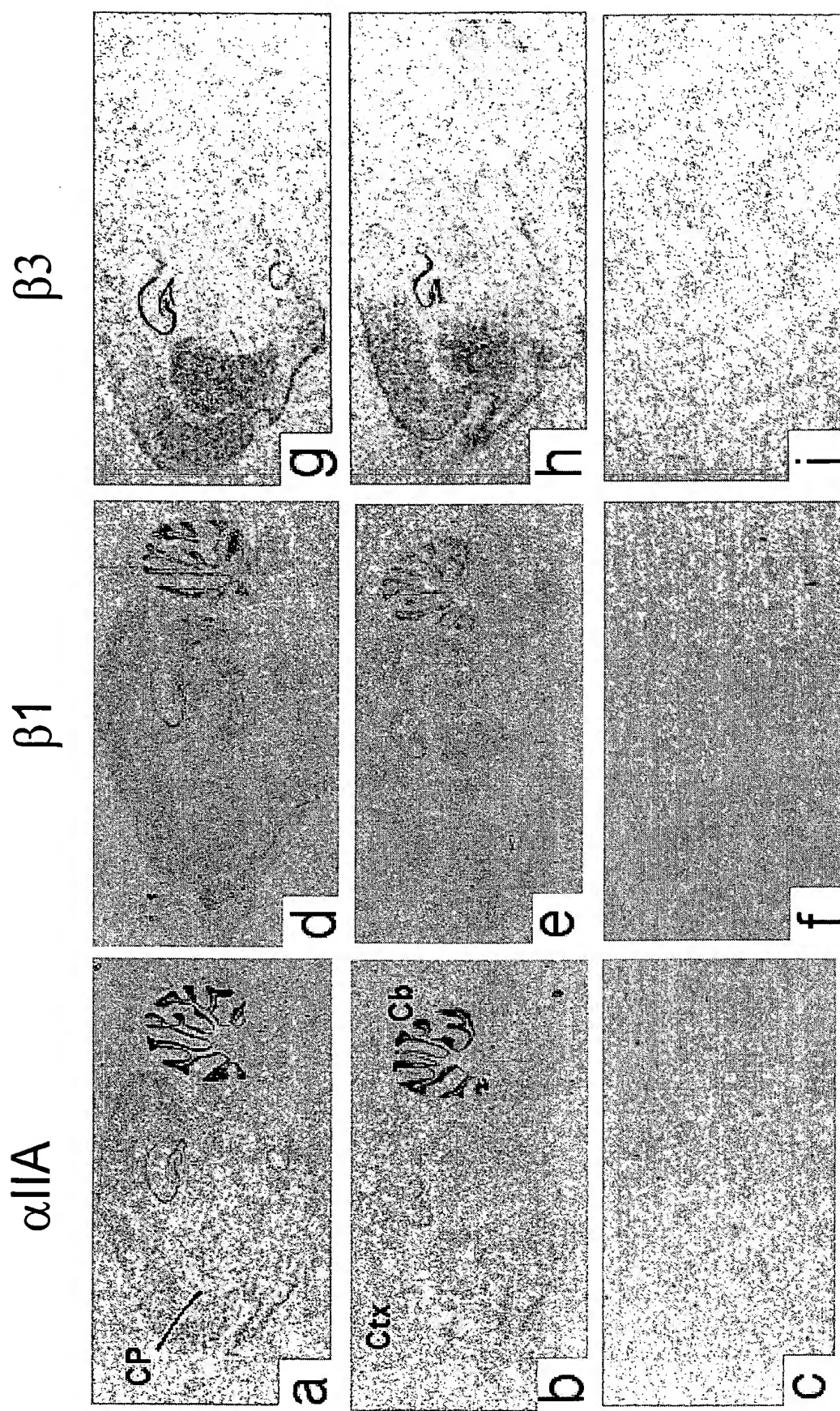


5 ng cDNA

0.5 ng cDNA

Figure 2

Figure 3



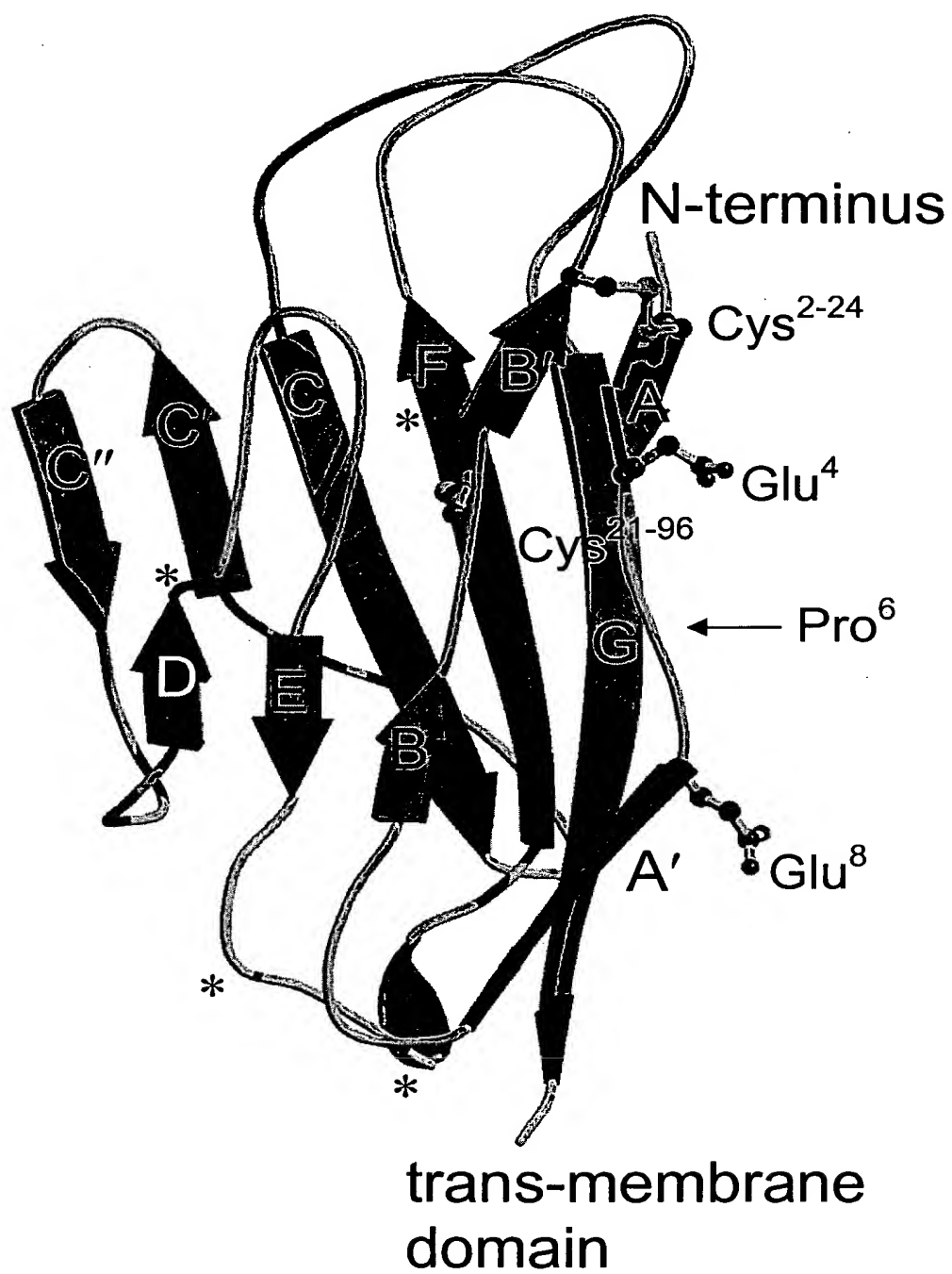
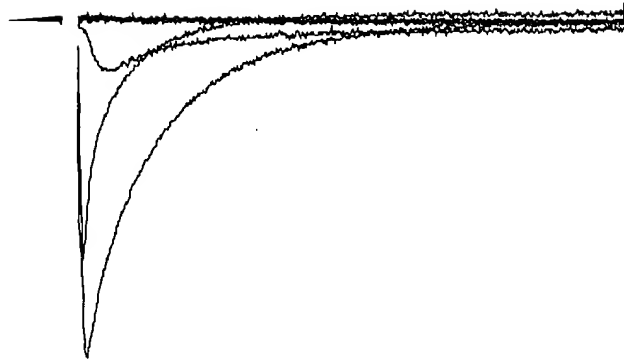
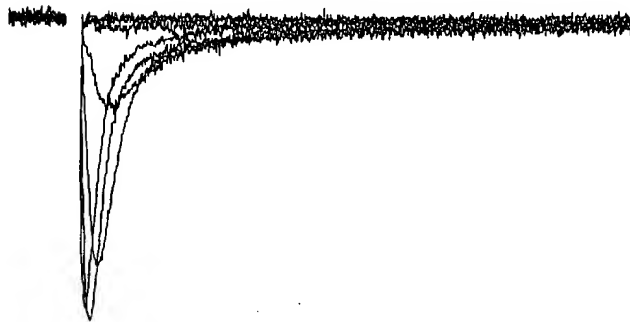
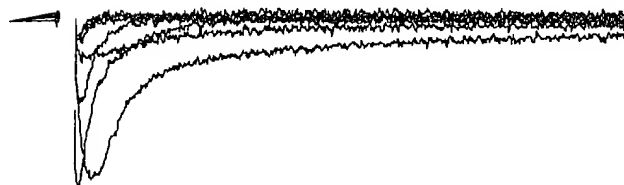
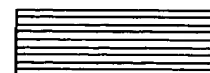


Figure 5

Figure 6**a** $\alpha-2$ **b** $\alpha-2 + \beta-1$ **c** $\alpha-2 + \beta-3$ 

100 nA



30

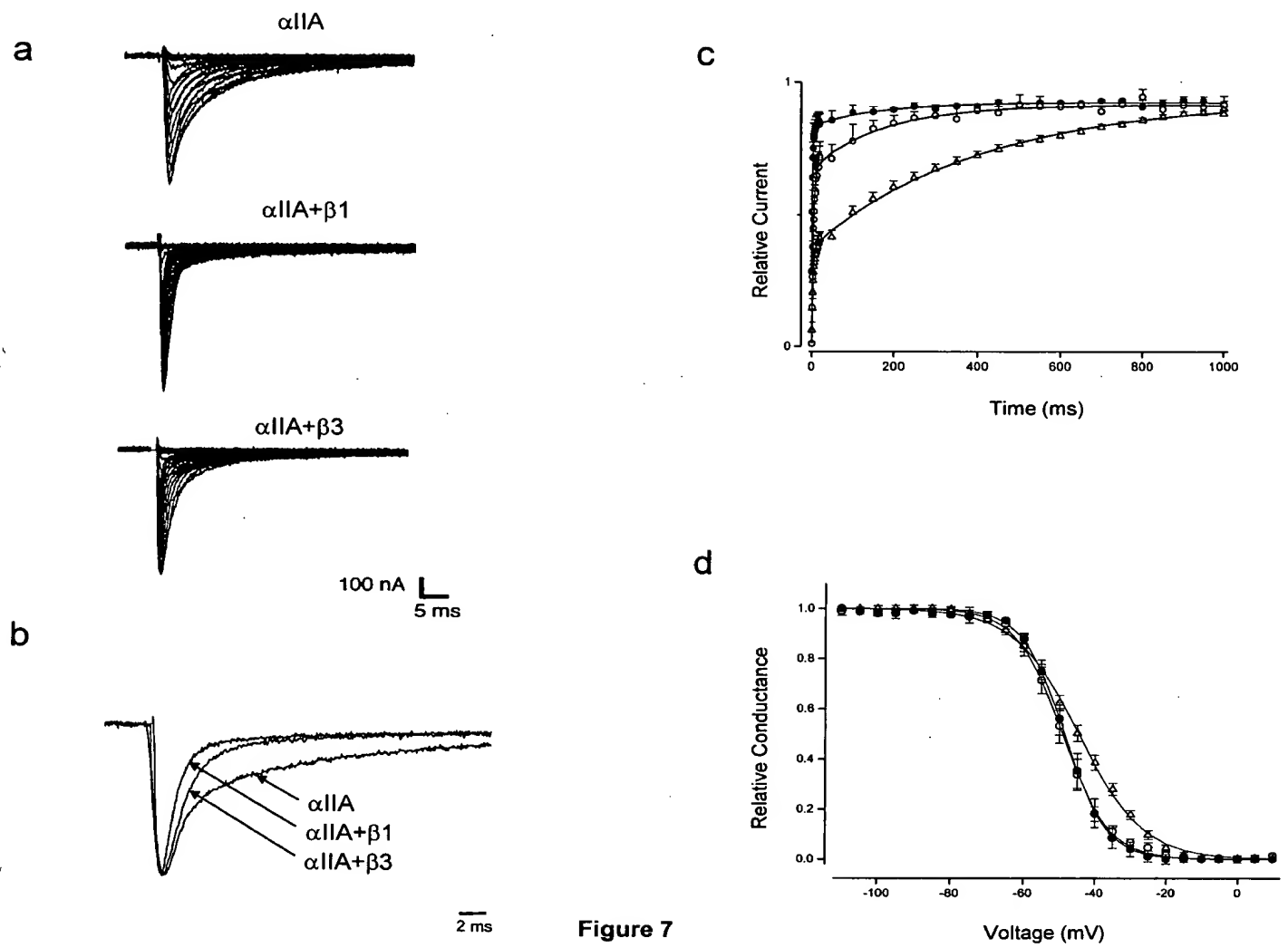


Figure 7

Δ : α IIA
 \bullet : α IIA+ β 1
 \circ : α IIA+ β 3

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